The e-RHIC Project

Powering Requirements of the Conceptual Design

Bob Lambiase

May 21, 2012

Overview of eRHIC

The purpose of eRHIC is to have the capability to collide heavy ions with leptons, such as electrons and polarized electrons. To do this, an accelerator is added to the 2.48 mile (4 km) RHIC tunnel that can accelerate electrons to 30 GeV.

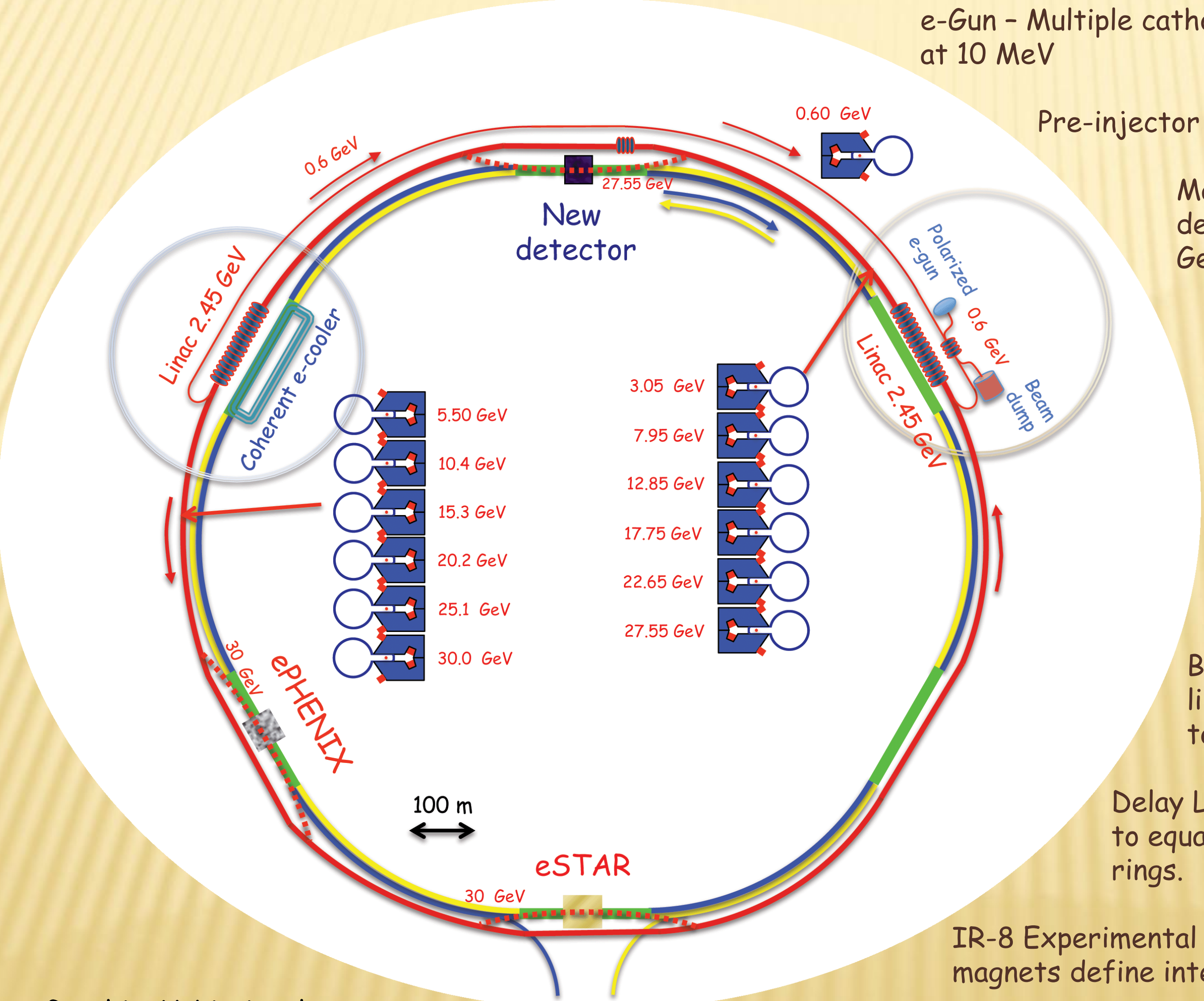
The electron rings use Energy Recovery LINACs (ERLs) in both the pre-accelerator and the main ring. In the pre-accelerator, the ERL reduces the amount of RF energy required to accelerate the high current beam to 0.6 GeV, as well as reducing the amount of energy the beam dump must absorb.

The ERLs in the main arcs deliver consistently high quality (luminosity) beam to the experiment. Prior to the collision, the electron beam has only traveled six times around the RHIC tunnel. Then, that beam has only one collision per experiment before having its energy recycled and dumped at low energies.

The luminosity of the heavy ion beam will be maintained by a Coherent e-Cooler (CeC). The CeC uses the interaction between the heavy ion beam and another electron beam.

I will present one design for eRHIC. Other designs are actively being explored.

The Components of eRHIC



Graphic: V. Litvinenko

e-Gun – Multiple cathode polarized source , 50 mA at 10 MeV

Pre-injector – 10 MeV to 0.6 GeV

Main LINACs – Each increase or decrease the beams by 2.45 GeV per pass.

Combiner / Spreader – Combines all six beams to enter LINAC, then spreads them out to individual beam lines.

Main Arc Magnets – Six separate rings, one for each energy.

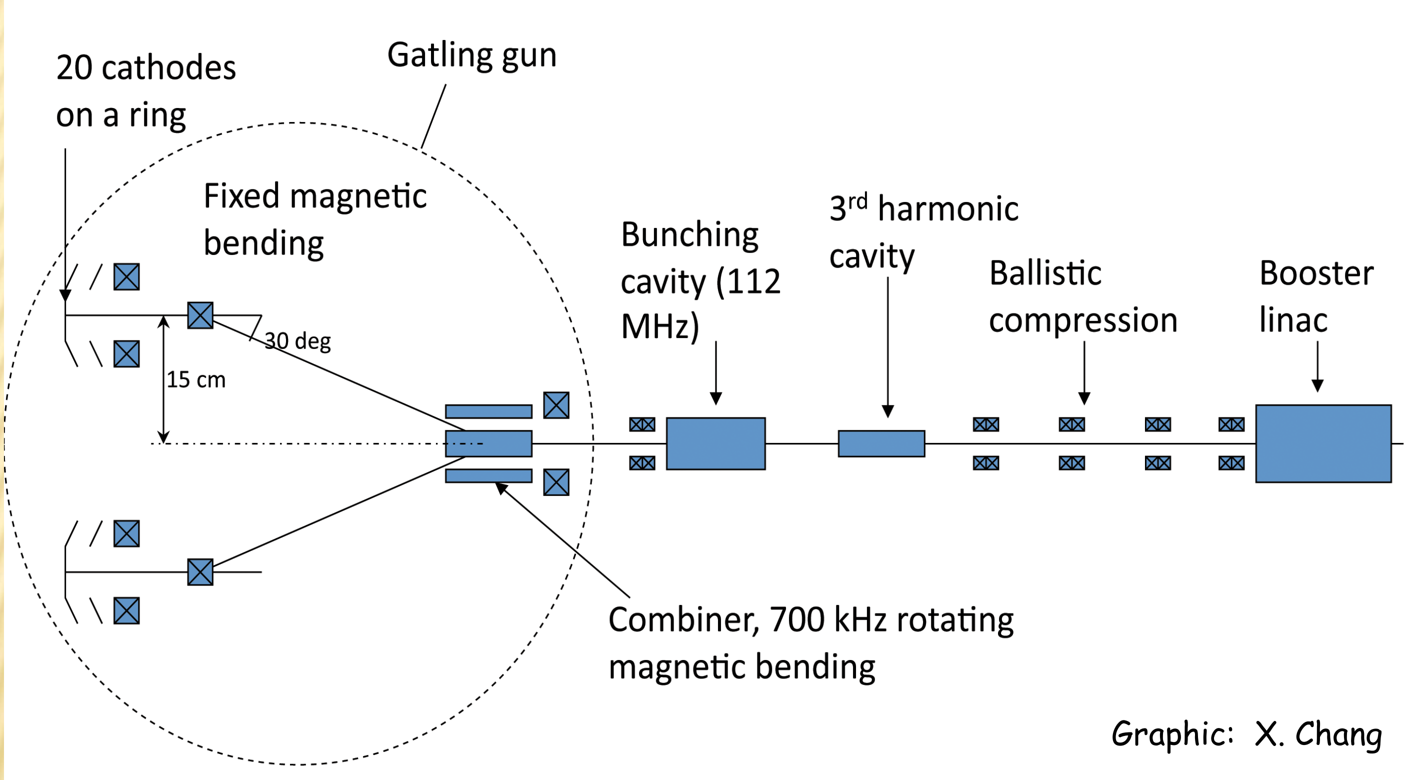
Bypass Lines – Lower energy lines separate from 30 GeV line to bypass experimental area.

Delay Lines – Vertically bent beams to equalize time of flight around rings.

IR-8 Experimental Magnets – Superconducting magnets define interaction.

Coherent e-Cooler – Maintains luminosity of the heavy ion beam.

The Polarized e-Gun



Twenty cathodes are arranged in a circular pattern. Each cathode is laser energized at a 700 kHz rate. By sequencing the 20 cathodes, beam pulses are produced at a 14 MHz rate.

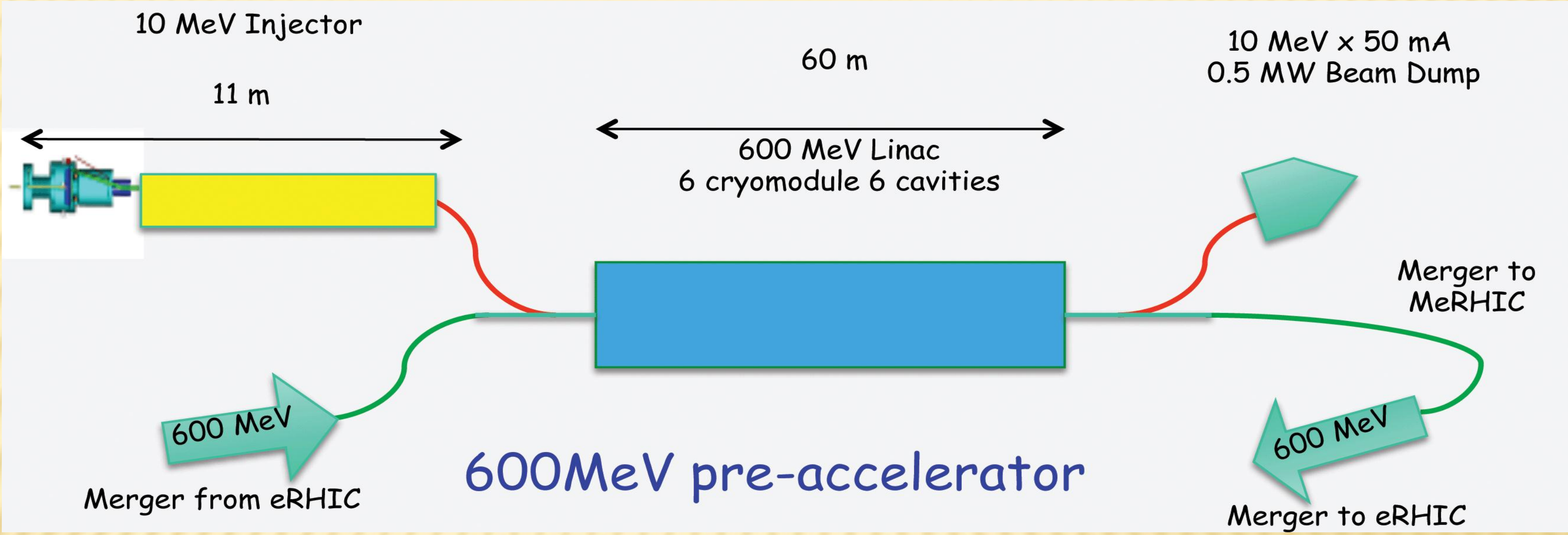
The combiner has both dipole and quadrupole windings. The dipole windings require 81 Amps at 3.5 kV, and about 120 W of losses. A resonating capacitor will be used to provide the reactive power.

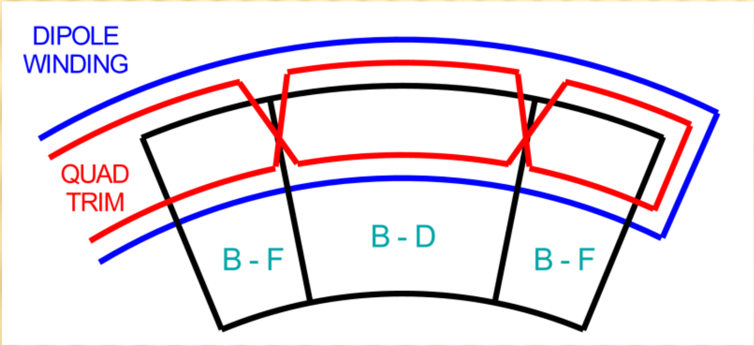
The cathodes operate at -250 kV. A low power electrode floats at 20 kV on top of the cathode potential.

It is planned to operate two of these is e-RHIC, switching them once per week, allowing maintenance.

The Pre-Injector

Pre-Accelerator Graphic: © D. Kayran, X. Chang

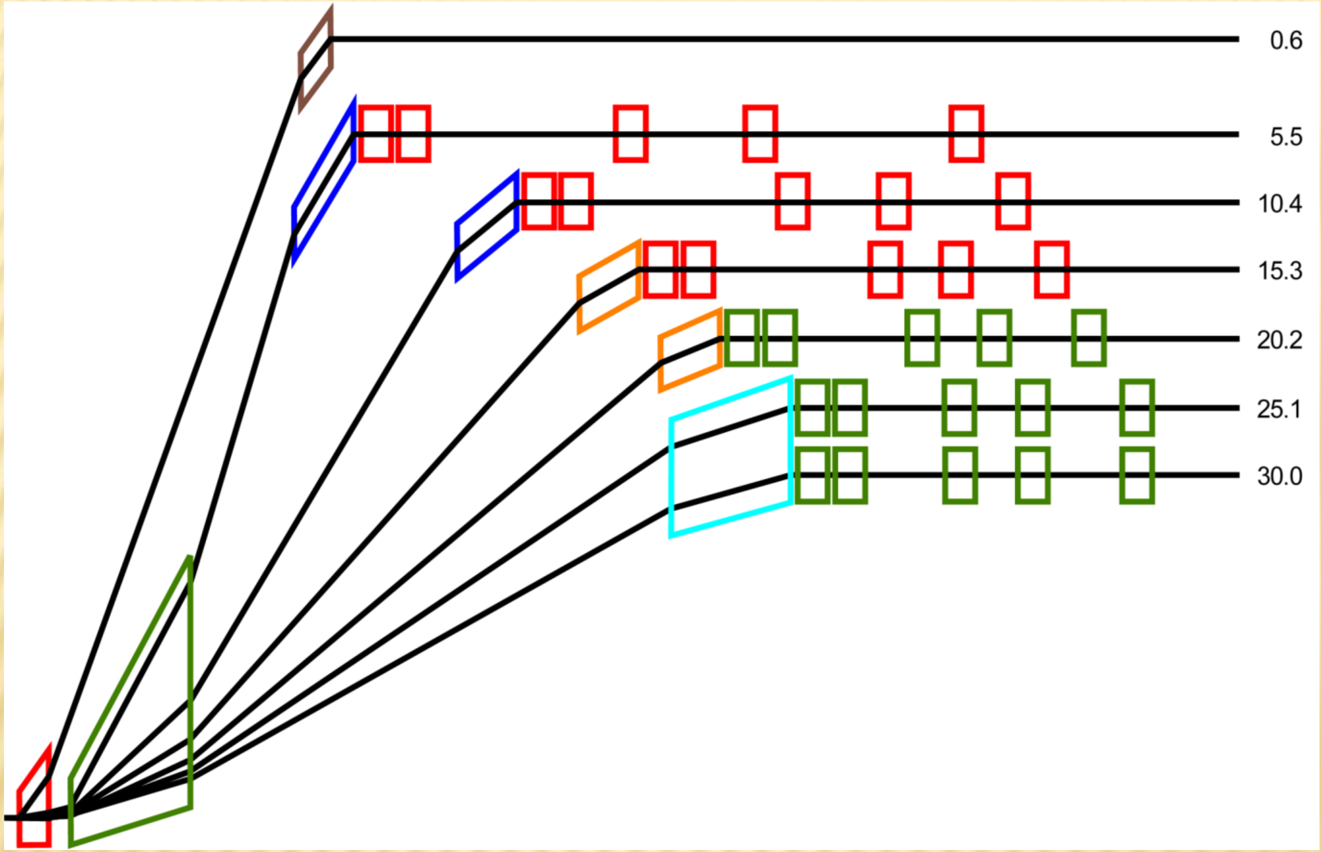




The ERL reduces the amount of RF energy required to accelerate the high current beam to 0.6 GeV, as well as reducing the amount of energy the beam dump must absorb.

The U-turn in the beam line to eRHIC uses combined function magnets with quadrupole trim winding.

Combiners and Spreaders



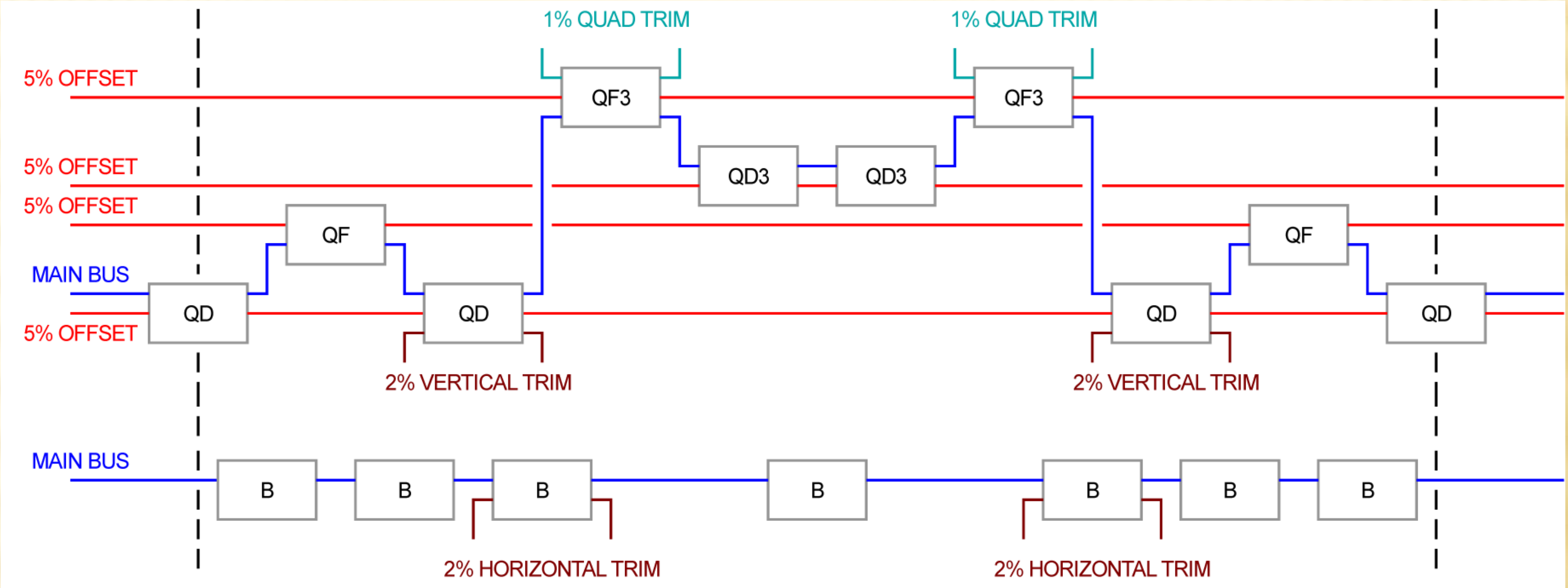
The combiner at 2:00 is shown. These magnets combine the beams from the six rings as well as the 0.6 GeV line from the pre-accelerator.

The splitter at 10:00 is the mirror image of this. At 10:00, the 0.6 GeV line feeds the beam line that returns to the electrons to the pre-accelerator ERL.

The splitter at 2:00 and the combiner at 10:00 are similar, but do not have a 0.6 GeV line.

Each magnet the spreader or combiner is individually powered. That means two things. First, there is a large number of units required. For all four parts, 150 power converts are needed. Second, since the loads are single magnets, they are relatively low impedance. Together, these two items mean these converters are costly and consume a lot of power.

Arc Magnet Strings



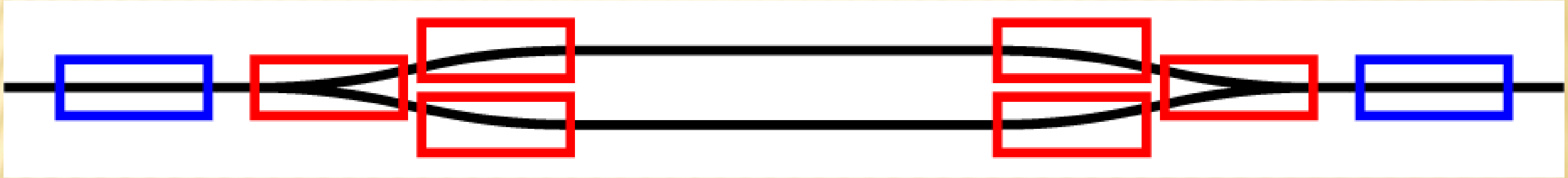
There is always an interaction between the magnet designer and the converter designer. Initially the dipole magnets were single turn and the quads had two turns. Even if the magnet has greater losses by increasing the number of turns, the net system losses can be much lower if the interconnection distances are long.

In eRHIC, we are connecting magnets six times around the ring (6 x 4 = 24km) plus trips back and forth to the equipment buildings. Multiplying the number of turns on the dipoles and quads increased the power in the magnet by 44%, due to insulation reducing available cross section , and because the cooling channels did not scale with the conductor size. But the net energy savings were more than a factor of two.

Bypass and Delay Lines

The bypass and delay lines span the regions between the arcs. There is a straight bypass line at 12:00, where there is no immediate plans for an experiment, a pass through bypass line at 6:00 (shown below) with provisions for an experiment, and a bypass line at 8:00 where additional magnets are inserted into the 30 GeV line.

The delay line is in the 4:00 region. The region between the arcs at 2:00 and 10:00 are filled the main LINACs and the spreaders and combiners.



The blue boxes represent a basic quadrupole block, as configured in the main arcs. Similarly, the red blocks represent a basic dipole block (seven dipoles with correctors), as configured in the main arcs. Five beam lines are bent one way, and the sixth is bent another way.

IR-8 Interaction Region

The interaction region at 8:00 is the only place we're adding superconducting magnets. Superconducting magnets are required here because they are needed to control the heavy ion beam.

We've considered both superconducting links (which is how we power the rest of RHIC) and warm bus, and right now warm bus seems to be the most economical.

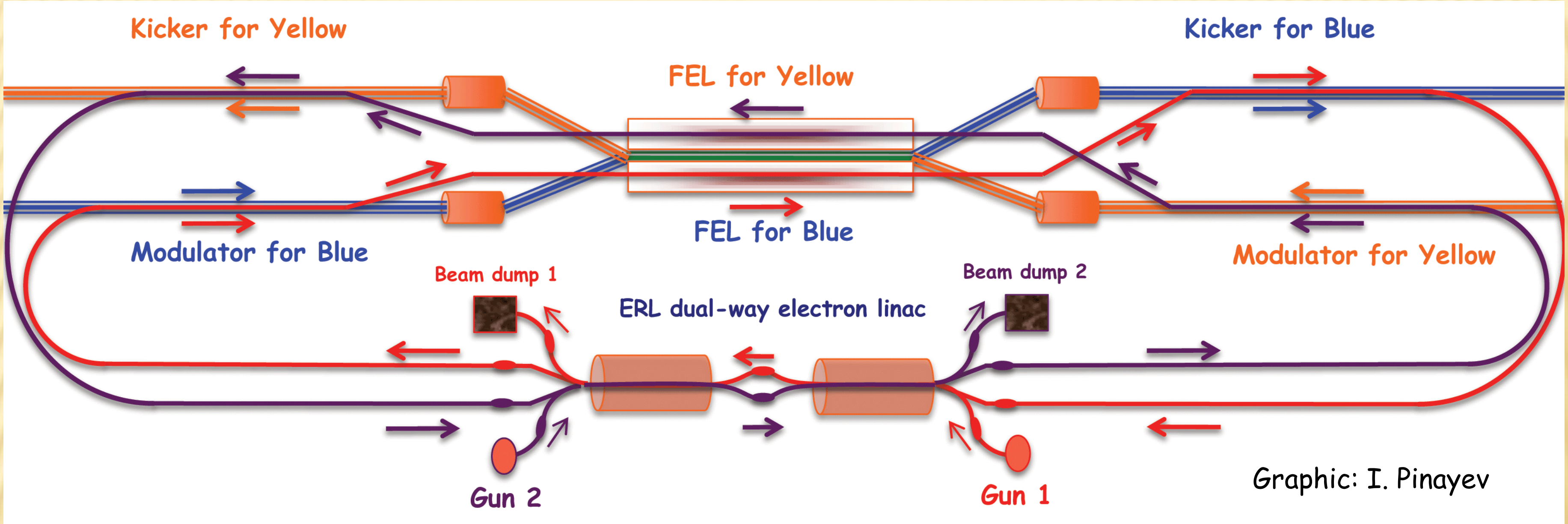
One of the interesting features of this region are the septum quads. The electron beam travels through a hole in the laminations. Compensation windings are used to null out any fields that might exist in that channel.

Except for the Compensation and trim windings, the mirror image magnets will be powered in series. For the larger superconducting windings, that will require a central quench protection assembly (QPA).

There are also warm magnets in this interaction region. These are used to move the beam into place and pass it though the septum magnets.

Magnet	Function	# of Windings	I, Amps
Q1	6.2T Combined Function Septum		
	Combined Function	1	1,600
Q2	90mm, 200 T/m LARP-like Septum Quad		
	Quadrupole	1	20,000
	Compensation	3	600
	Trim	2	90
Q3	120 mm, 200 T/m LARP-like Septum Quad		
	Quadrupole	1	20,000
	Compensation	3	600
	Trim	2	90
BON	DX-like Dipole, Shielded Penetration Through SS Collars.		
	Dipole	1	4,500
	Trim	2	90

Coherent electron Cooling (CeC)



This diagram shows how CeC is built for collisions of two heavy ion beams. For eRHIC, only one of these coolers would be used. But the graphic shows all the elements.

To cool the blue beam, we start at electron Gun 1. These electrons are accelerated in the ERL using the energy from the previous beam. It then merges with the blue ion beam in the modulator region. Here the ion beam modulates the electrons. The electron and ion beams are separated. The electron beam passes through a permanent magnet FEL, where the modulation is amplified. Then the electron beams are recombined, where the highly modulated electrons cool the ion beam.

After that, the electron beam separates from the ion beam where its energy is returned to the ERL, and is deposited in Beam dump 1.