Design and Manufacture of Tunable Permanent Magnet Based Quadrupole for Next Generation Electron-Ion Colliders

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Program Managers: Manouchehr Farkhondeh & Michelle Shinn

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Outline

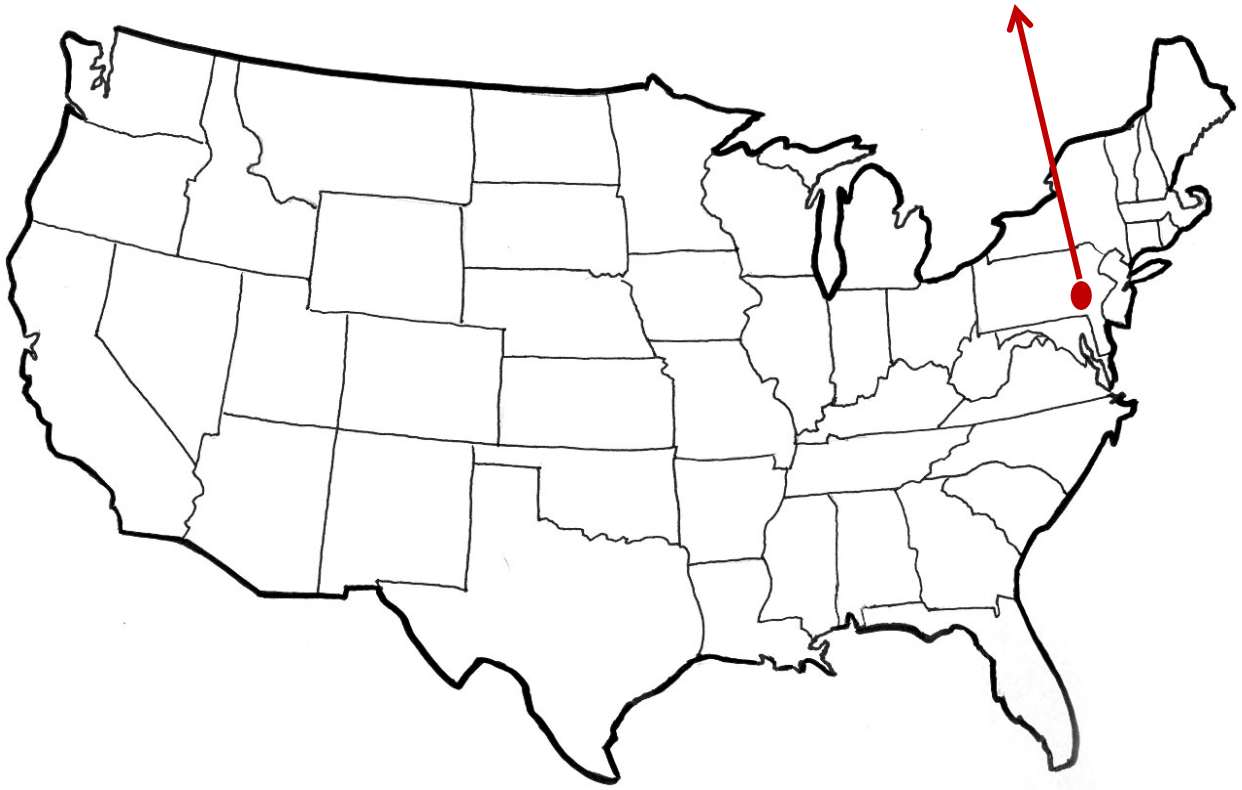
1. EEC Introduction
2. Project Description
3. Achievements
4. Schedule & Deliverables

1. EEC Introduction

World's First Rare Earth Permanent Magnet Producer

Lancaster, PA

EEC is the only vertically integrated SmCo magnet producer in the US.



The EEC story

EEC is founded in 1970 *(in a Milk House with 2 employees)* as Marlin Walmer pioneered the processing and subsequent commercialization of an entirely new class of permanent magnets (SmCo)

40,000 square foot facility was built to support the steady growth of business from 1970-1985

Add a new 45,000 square foot facility now housing the magnet finishing operation

EEC opens European Sales Office in Almelo, The Netherlands

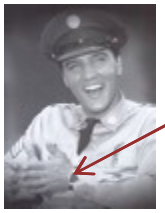
EEC received >25 SBIRs & STTRs awards since 1996 from NASA, DOE, NSF, EPA, and DOD

(Rapid growth of business)

1960's — **Founder Marlin Walmer is working at Hamilton Watch pioneering platinum-cobalt magnets** for the world's first electric watches

1970

1972 — **Moved to 10,000 square foot facility** on Main St. Landisville



Hamilton Watch's 1st electric watch named the "Ventura"…made famous by Elvis Presley.

Mid 70's — **Developed Temperature Compensated SmCo** that have near-zero change in magnetic field over temperature changes

1985

2002 — **Patented Ultra-High Temp SmCo 2:17 magnets** in 2002 which operate at temperatures up to 550°C

2012

2012 — EEC "Milk House" is recognized as an **ASM Historical Landmark**

2014

2015 — **EEC invests in additional equipment** to meet increasing demand

2015

2017 — **New plant layout to optimize floorplan and Equipment**

Specialists in Rare Earth Magnets and Magnet Systems

EEC Applications

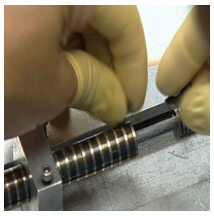
Product Platforms

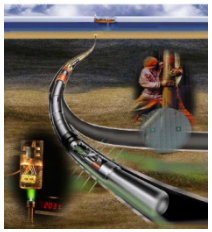
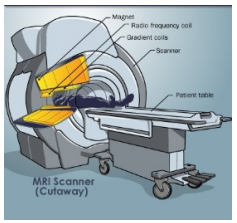
Samarium Cobalt ■ Neodymium-Iron-Boron ■ Alnico ■ Ceramic ■ Assemblies

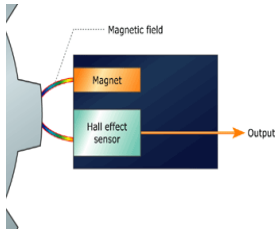
EEC

Magnet Components

Magnet Assemblies





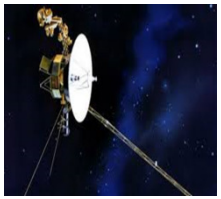
CUSTOMERS

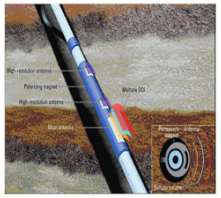
Markets

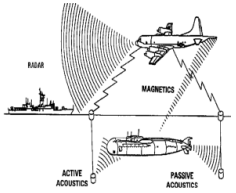
Defense

Communications | Aerospace | Motion | Instrumentation | Medical | Sensors

Applications



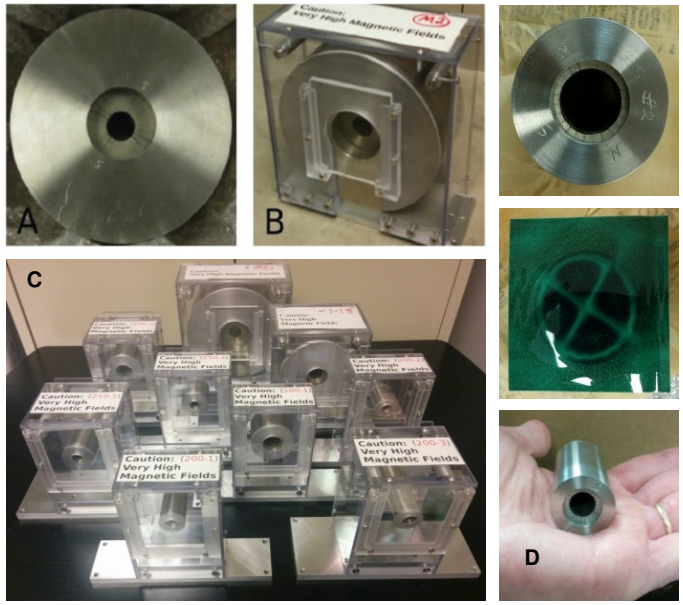


TWT, Circulators& Isolators | Gyroscopes Accelerometers | Motors Generators | NMR Oil & Gas Exploration | MRI for medical | Sensors

EEC Applications

Quadrupole Magnet for Proton Therapy

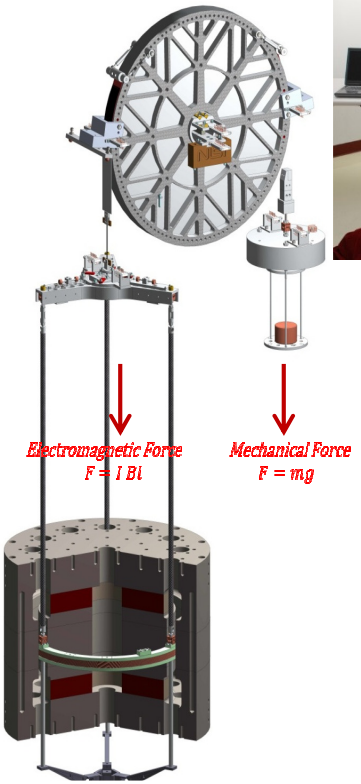
- **Proton radiosurgery** to treat brain tumor metastasis.
- **Magnetic focusing** of the proton beam could be used to reduce this particle scattering leading to **improved dose distributions, dose rate and more efficient dose delivery.**



Focusing magnets consist of 24 segments of Sm_2Co_{17} positioned into Halbach cylinders. [H. Choi, et al., '**Design and Development of Permanent Magnet Based Quadrupole for Proton Radiosurgery Applications**', *24th Int. Workshop on Rare Earth and Future Permanent Magnets and Their Applications (REPM 2016)*, Darmstadt, Germany.

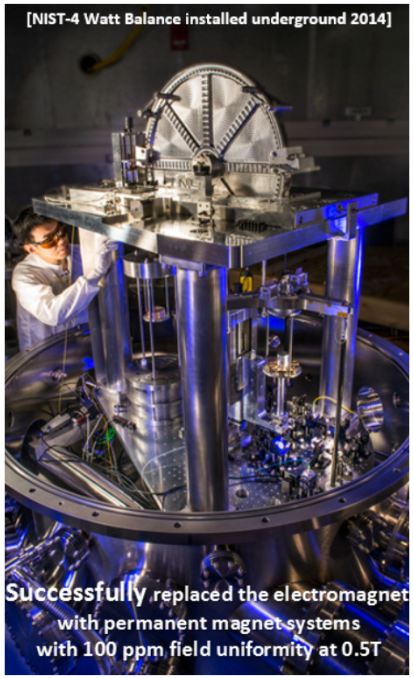
Permanent Magnet Assembly for Watt Balance

- **Watt Balance** is an electromechanical weight measuring instrument to define a kilogram mass by comparing electrical power to mechanical power.



[Graphic courtesy of NIST]

NIST Watt Balance PM assembly ~ 1800 lb.



2. Project Description

Project Background

- This project is for the design and construction of a prototype **quadrupole permanent magnet** for the magnet transport lattice for an electron-ion collider.

The Nuclear Science of *eRHIC at BNL*

- Construction of eRHIC at BNL will have a major impact on the Electron Ion Collider (EIC) physics program, advancing the long-term vision for better understanding and new discoveries in Quantum Chromodynamics (QCD) theory.
- The use of permanent magnet based technology will significantly reduce the cost and maintenance problems of particle accelerators.

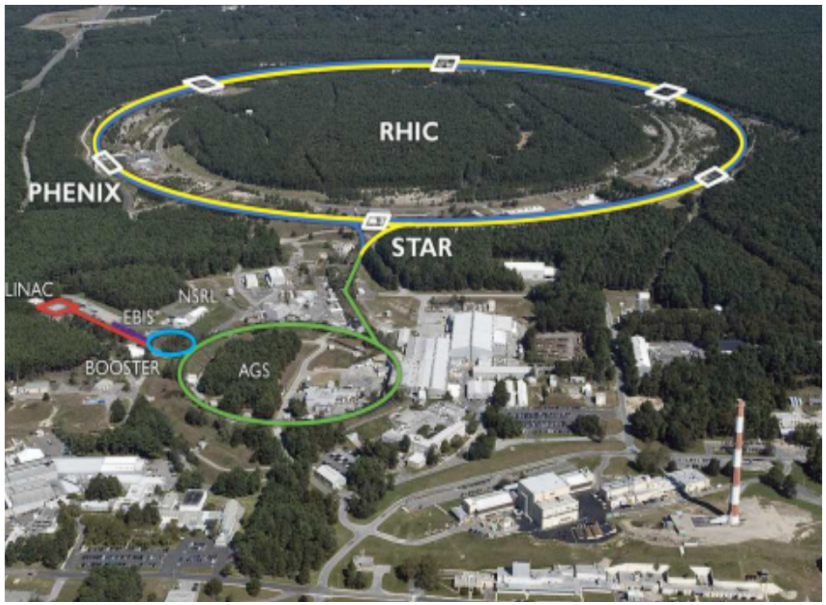
Other Applications of Accelerator Science, using Permanent Magnets

- Therapy of advanced tumors, the production of radiopharmaceuticals and medical isotopes through ion implantation, non-invasive security inspections of closed cargo containers, etc.

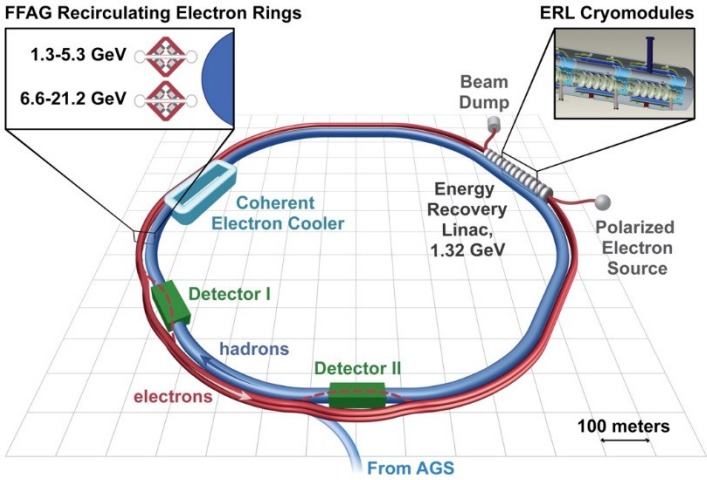
2. Project Description

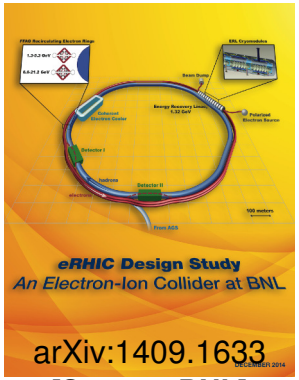
Electron Relativistic Heavy Ion Collider Configuration at BNL

RHIC, BNL

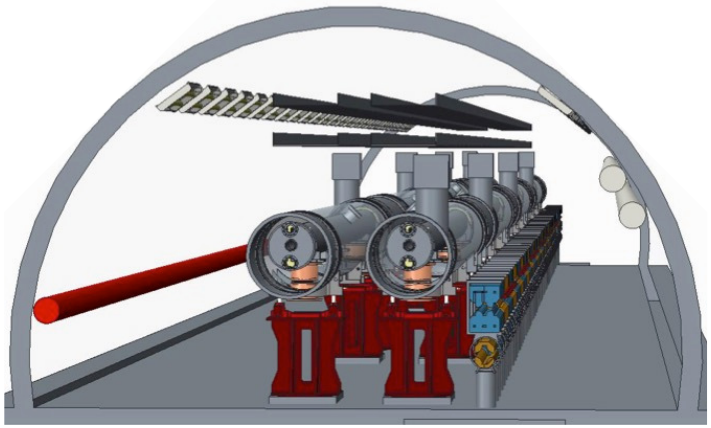


❑ Circumference ~ 3.8 km (~ 2.3 mi.)





[Source: BNL]



Future Electron Ion Collider Development

Goals

1. Manufacture prototype quadrupole assembly using permanent magnets.
2. Projects of interest:
   - eRHIC Electron Ion Collider in the present RHIC tunnel.
   - Proton therapy for medical treatment.

Why Permanent Magnets?

1. No power consumption results in significant construction, operation and maintenance cost reduction.
2. Occupy small volume as compared to the electromagnets producing the same useful magnetic field.

Objectives

1. Conduct design, construction, and testing of a tunable focusing quadrupole magnet prototype with high performance at low cost using robust industrial technologies.
2. Achieve specifications (Field gradients 34.42 T/m, Field gradient error ≤ 0.1%, Good field region R13.4+2mm)

3. Achievements

Task 1: Magnet Design Finalization – Completed (presented @ 2017 Meeting)

Task 2: 1st Magnet Prototyping – Completed in 2017~2018

Task 3: 1st Magnet Measurement and Testing – Completed in 2018

3.1. Measure magnetic field gradient using 2D / 3D Hall probe on XYZ station.
3.2. Check mechanical alignment using FARO laser tracker.
3.3. Check field harmonics using harmonic coil at BNL.
3.4. Conduct magnetic field correction with built-in adjusting features in-situ at BNL.

Task 4: 2nd Magnet Design and Development – Q7~Q8 Future Work

4.1. Refine the 2nd magnet design based on the 1st prototype results.
4.2. Produce the 2nd magnet assembly.

Task 5: 2nd Magnet Field Testing and Delivery – Q8 Future Work

5.1. Verify magnetic field performance and make final adjustment.
5.2. Deliver to BNL for beam performance evaluation.

Modular Magnet Configuration

300-mm Long Magnet Assembly with Adjusting Mechanism

Section removed
Company proprietary

- FEA demonstrated that all targeted specifications were achieved: field gradient 34.42 T/m, field gradient error ≤ 0.1%, good field harmonics.

Magnetic Design

3D Nonlinear FEA Field Contour Map of 300-mm Long Magnet Assembly

Section removed
Company proprietary

Modular Magnet Test

100-mm Long, 12 Modular Magnets Uniformity Test

Section removed
Company proprietary

Quadrupole Magnet Assembly

300-mm Long Quadrupole Magnet Built Successfully at EEC

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Field Gradient Test Setup

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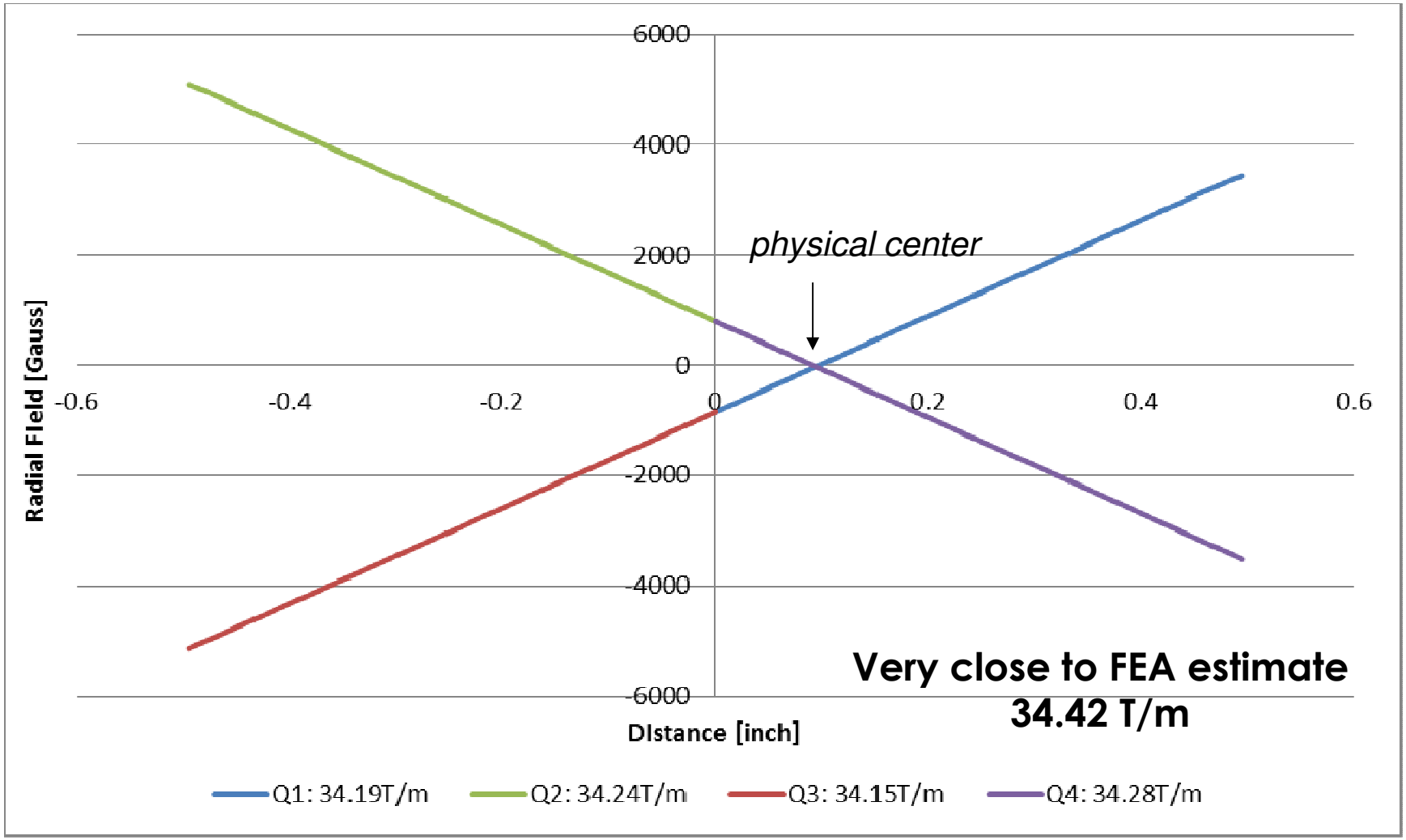
Field Gradient Test Results

Field Gradient Data of As-is Magnet without Adjustment



Field Harmonics Test Setup

Field Harmonics of 1st magnet was tested using harmonic coil

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Field Harmonics Test Results

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Company proprietary

Field Harmonics Test Results

Section removed
Company proprietary

Non-Symmetry Effects

Section removed

4. Schedule & Deliverables

Task	Milestone Description	%of time	Year 1				Year 2			
1	HER magnet design finalization	10								
2	HER 1st magnet prototyping	30								
3	HER 1st magnet testing	15								
4	HER 2nd magnet fine tuning and production	30								
5	HER 2nd magnet testing and delivery	10								
6	Report	5								

Future Works

1. **2nd Magnet Production –** Fabricate the 2nd quadrupole magnet based on the 1st magnet. (Completion Date: 10/31/18).
2. **2nd Magnet Test –** Conduct the 2nd magnet field harmonics test. (Completion Date: 11/16/18).