Solenoid Magnet for Detector 1- BaBAR and New Solenoid

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L3 CAM, Detector Magnet

Detector Integration Meeting

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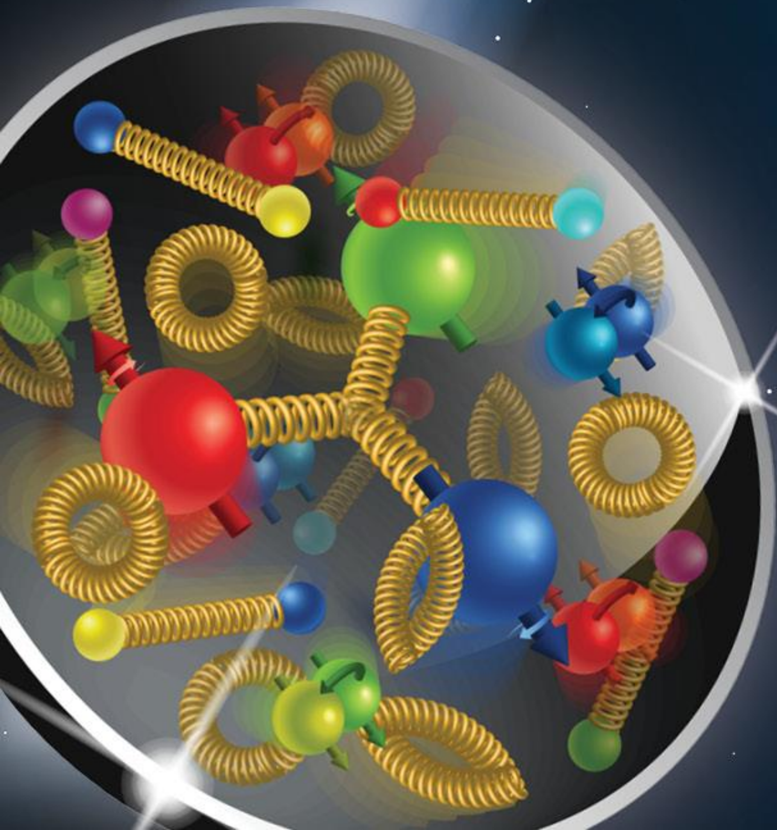

Electron-Ion Collider

Brookhaven National Laboratory   Jefferson Lab   U.S. Department of Energy | Office of Science

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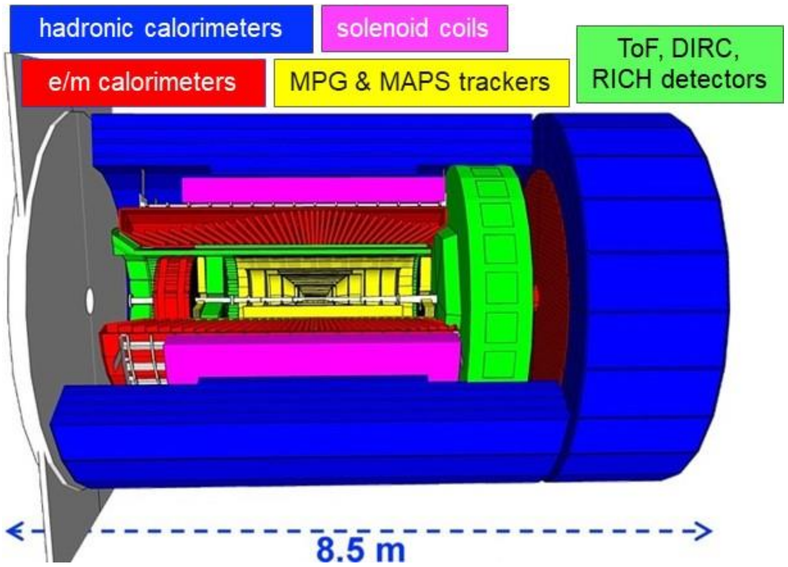
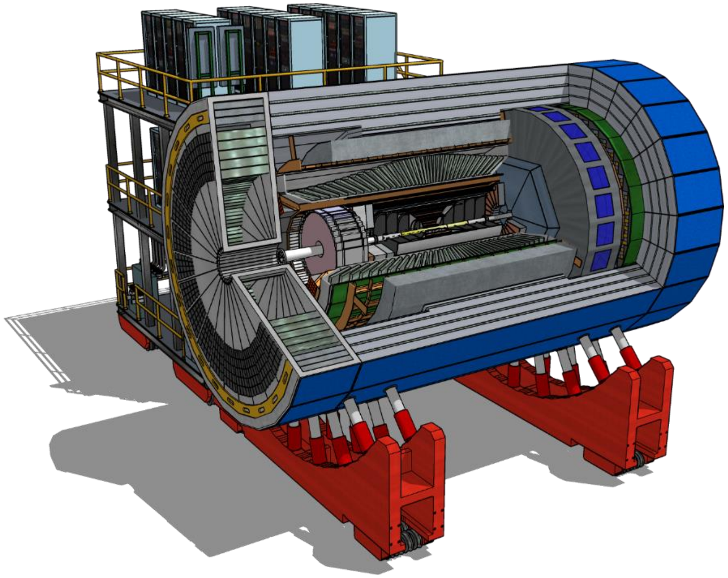
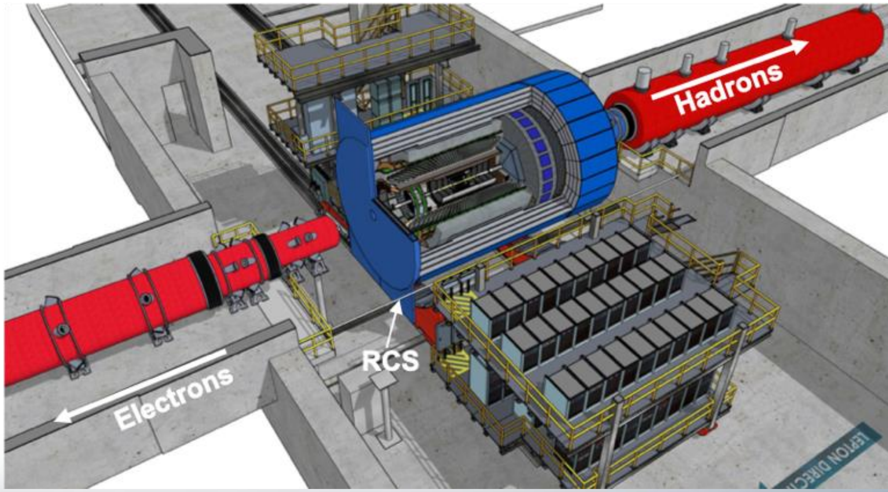
Detector-1



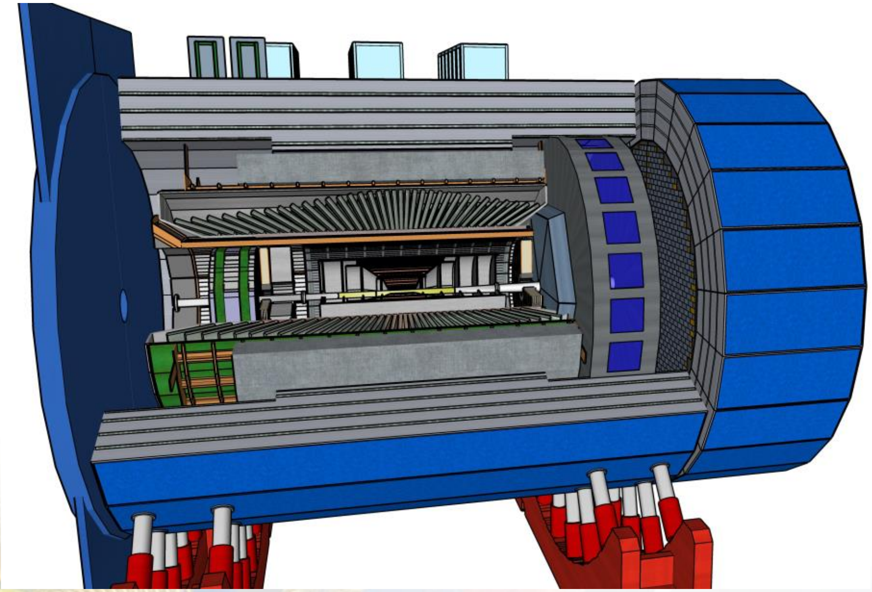


Parameter	Detector 1- ECCE
Status	Old BaBAR/sPHENIX magnet New magnet as risk mitigation
Central Field (T)	1.5
Warm bore diameter (m)	2.84
Coil Length (m)	3.5
Operating Temperature (K)	4.5
Stored Energy (MJ)	27
Conductor	Aluminum Stabilized NbTi Rutherford cable Copper Stabilized NbTi Rutherford cable



1.5 T BaBAR/ sPHENIX magnet- History

- Detector-1 is based on ECCE detector proposal, ECCE planned to re-use the existing 1.5 T BABAR magnet as the detector solenoid for the EIC project.
- The magnet for the BABAR experiment at PEP-II at SLAC, CA was manufactured by Ansaldo, Italy in 1997 and was commissioned in 1998
- It was then transferred to BNL, NY in 2015 for use in the sPHENIX experiment.



- Magnet History
  - November 1997- Factory Acceptance test at Ansaldo, Italy
  - March 1998- Final Commissioning at SLAC
  - April 2008-BaBAR run ends
  - February 2015-Magnet arrived at BNL
  - March 2016- 100 A test
  - February 2018- tested to 4830 A
  - Plan to energize the magnet to full current before sPHENIX Run

The BaBAR/sPHENIX Magnet

- The BaBar superconducting solenoid will be repurposed for the detector-1.
  - The BaBar magnet is already at BNL for use by the sPHENIX experiment.
- Detector-1 also plans to reuse the surrounding combined hadronic calorimeter and flux containment system for this magnet
- This provides the 1.4 T field that suffices to do the EIC science with an AI optimized detector

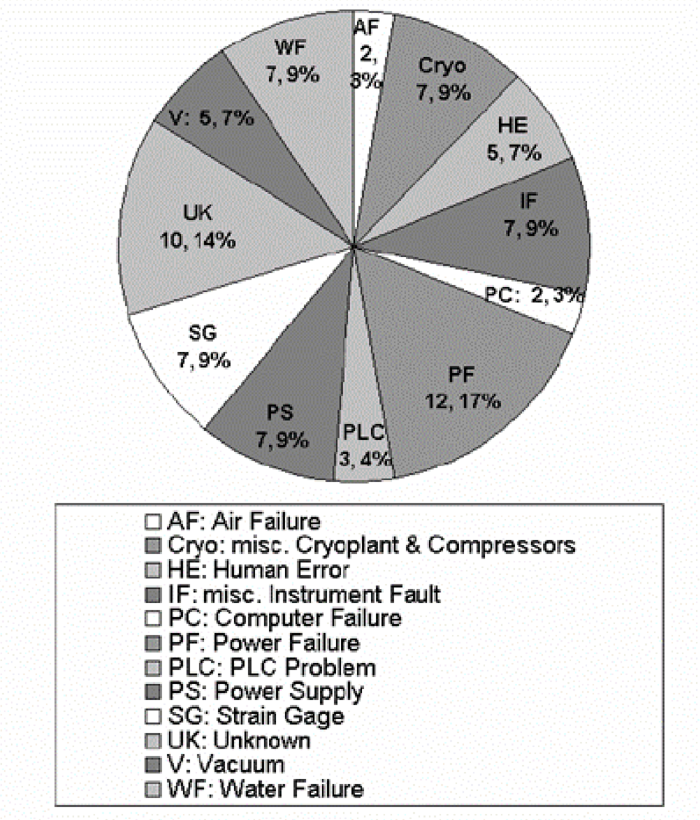
Central Induction	1.5 T* (1.4 T in ECCE flux return)
Conductor Peak Field	2.3 T
Winding structure	Two layers, graded current density
Uniformity in tracking region	±3%
Winding Length	3512 mm *at R.T.*
Winding mean radius	1530 mm *at R.T.*
Operating Current	4596 A (4650 A*)
Inductance	2.57 H (2.56 H*)
Stored Energy	27 MJ
Total Turns	1067
Total Length of Conductor	10,300 m

* Design Value

- *The warm bore diameter of 2.84m and coil length of 3.512 m corresponds to a 39 deg angle, this covers the required region covered by the barrel detectors in the YR (~40 deg angle).*
- *Reuse of a magnet can induce risk, there is a plan to mitigate this risk.*

sPHENIX Magnet-SLAC Risk Analysis (2004, 2006)

- The magnet started operation in May 1999. Two formal risk assessments were carried out at SLAC in 2004 and 2006 following 5 to 7 years of operation.
- From May 1999 – 2004, there have been 63 unplanned interruptions to magnet operations. None of these can be shown to be the result of a spontaneous quench in the coil. In nearly all cases, the interruptions can be traced to failures in utilities or supporting systems or to human error. Three notable categories-
    - Unknown: 10%
    - Miscellaneous instrument faults : 8%
    - Strain gauges: 8 %
- After mitigations were implemented – namely installing cooling and vacuum backup systems, changing the control programming and removing unneeded interlocks – the total number of interruptions after 2004 has been significantly reduced.
- Magnet availability between 2000 – 2004: approx. 98%



sPHENIX Magnet- BNL High Current Test (4830 A)

The high field test was carried out after installation of a return flux steel box enclosing the superconducting magnet. The magnet achieved field – the following issues were noted:

- Several voltage taps (used for quench protection) failed before the test commenced
- New temperature sensors were fitted prior to the test but failed to read accurately
- Another voltage tap failed intermittently and caused a fast dump of the magnet
- The control system crashed causing a fast dump of the magnet
- Quench occurred at about 3000 A
- Quench occurred at about 4410 A (possibly due to the high ramp rate of 2.5 A/s)
- Achieved 4830 A after reducing ramp rates
- Magnet only stayed at full field for 36 minutes due to the lack of availability of LHe
- Multiple hardware issues (mostly external to the magnet) were noted and will be addressed prior to the sPHENIX experimental runs.
- However, there were a few leaks, most of which were accessed and repaired. But there is still one small cold leak which is currently being managed by pumping
  - There is also evidence that both Ansaldo and SLAC had previous issues with leaks

BaBAR magnet- JLab Risk Analysis

Executive Summary

Purely from an engineering perspective, if the changes (improvements) listed in the risk document are carried out in order to mitigate the identified risks, then this magnet should be suitable for prolonged use as part of the detector system for the EIC project. However, it should be borne in mind that several of the mitigation efforts involve the disassembly of the magnet and this therefore imposes a certain level of risk. Furthermore, if the physics studies currently underway, indicate that additional changes are required to the magnet, then the system as a whole, will have to be re-evaluated - to ensure that the magnet remains within the original design limits under both normal and abnormal operating conditions.

Risk Rating	Before Risk Mitigation	After Risk Mitigation	Comments
HIGH	1	0	
MODERATE	5	4	Requires disassembly which can introduce additional risk
LOW	2	4	
Total	**8**	**8**	

BaBAR magnet- JLab Risk Mitigation

Sub-System	Present Status	Failure Modes / Performance Limitations	Risk Rating Before Mitigation	Risk Mitigation	Risk Rating After Mitigation
Coil Protection	Standard design utilizing external dump resistor. VT11 open circuit, VT10 suspect – might affect quench detection and protection. Temperature sensors on splices reading high possibly due to poor mounting.	Additional critical voltage taps (for quench detection and protection) could be lost. Temperature sensors in key areas – coils, splices and current leads could either be lost or mis-read. If the power supply, dump switch and dump resistor are original, they could fail.	**HIGH**	Purchase new magnet power supply, dump switch and dump resistor. BNL confirmed that they have refurbished the power supply (including the capacitors etc.) and the dump resistor (including the contactor and have added a snubber circuit) before the high-field test. Add new redundant VTs and new temperature sensors or remount existing sensors – **requires disassembly of magnet.**	MODERATE **(risk could be incurred as soldering new VTs to magnet conductor can be troublesome and might cause damage to the conductor and insulation)**
Internal Mechanical Support System	Five strain gauges are not working and one shows unusually high readings and is ignored during tests.	If tie rods, disc springs have been overstressed, they could fail in the future although this is difficult to surmise as several gauges are not working and at least one is being ignored. There could have been some overstressing of components during the transport from SLAC to BNL although there are no outward signs of this at present.	MODERATE	Fit new strain gauges – properly mounted and temperature compensated - **requires disassembly of magnet.**	MODERATE **(remains as moderate as the magnet requires disassembly which could lead to more rework)**
Internal Cryogenic Cooling System	Potential hard touch between inner thermal shield and helium vessel (temp sensor on shield reading 4.2 K). Internal leak when cold: 10^{-6} to 10^{-7} torr-liters/sec level – presently being managed by pumping	Additional thermal shorts occur increasing the heat load on the system. Existing leak gets worse or additional leaks open up. There is some indication that both Ansaldo and SLAC struggled with making certain joints leak tight. There could have been some overstressing of components (e.g. welds between cooling tubes and the coil support tube) during the transport from SLAC to BNL although there are no outward signs of this at present.	MODERATE	Fix leaks, survey all pipe work to ensure all joints are leak tight and no damage has been sustained by the years of operation and the transport from SLAC to BNL - **requires disassembly of magnet.**	MODERATE **(remains as moderate as the magnet requires disassembly which could lead to more rework and the leak may be difficult to locate)**
Instrumentation	Strain gauges not working, temperature sensors on splices reading high, critical voltage taps lost or suspect.	Additional instrumentation could be lost or start mis-reading	MODERATE	Fix instrumentation - **requires disassembly of magnet.**	MODERATE **(remains as moderate as the magnet requires disassembly which could lead to more rework)**

sPHENIX Magnet- JLab Risk Analysis-Recommendations

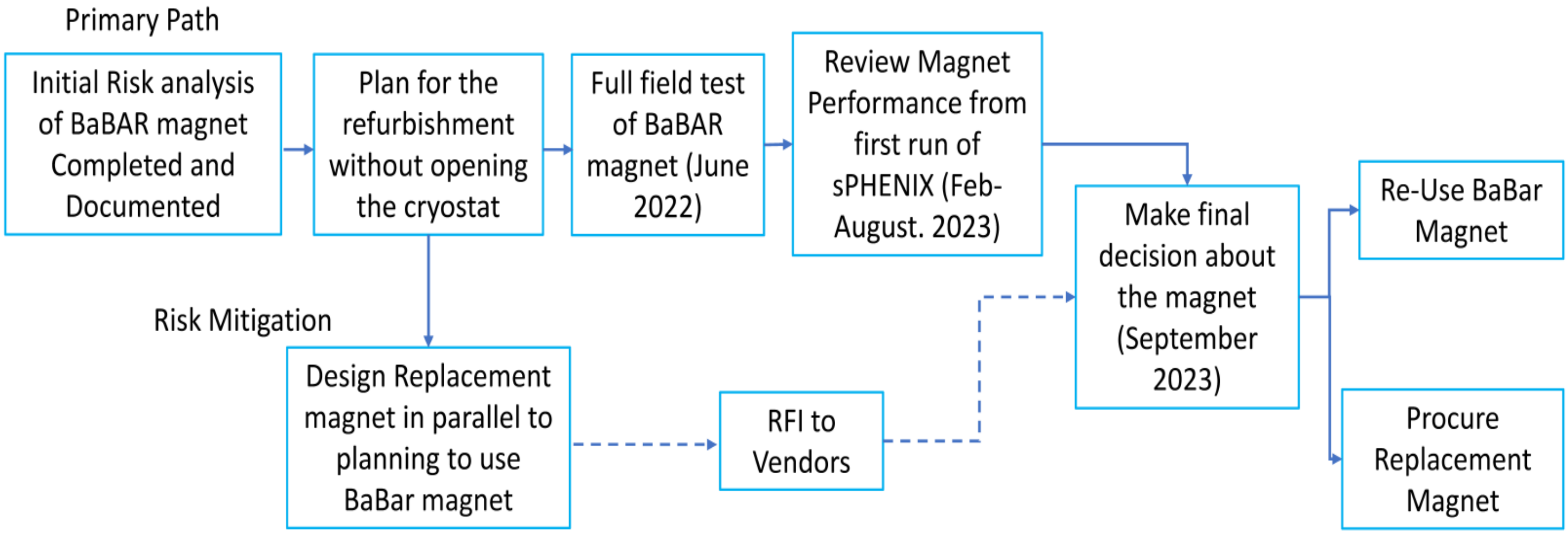
To provide a sufficiently high level of confidence in the reliability of this magnet (from an engineering point of view), the magnet should be refurbished as suggested below.

1. The magnet should be disassembled sufficiently:
    - To allow the existing multi-layer insulation (MLI) to be removed and replaced with new MLI.
    - To allow inspection of the superconductor coil block – resin and insulation system.
    - To allow inspection and if necessary, repair of insulation and support of any internal bus bars.
    - To allow all cooling pipe work and welds to the coil support tube to be inspected and all leaks repaired.
    - To allow inspection of the thermal shield and cooling pipework ad welds.
    - To allow inspection of all vacuum seals and welds.
    - To allow inspection of all accessible conductor splices in particular the ones between the coil and the current leads.
    - To allow inspection and if necessary, replacement of insulating components – e.g. G10 collars, plates, etc.
    - To allow inspection and if necessary, replacement of the magnet current leads.
    - To allow broken voltage taps to be repaired and additional redundant taps installed.
    - To allow temperature sensors which are presently possibly malfunctioning to be either repaired or replaced.
    - To allow additional or redundant temperature sensors to be installed
    - To allow malfunctioning strain gauges to be either repaired or replaced.
    - To allow additional or redundant strain gauges to be installed.
    - To allow a full inspection and if necessary, replacement of the tie rods and disc springs for the internal mechanical support system.
2. If the valve box is to be re-used, it should also be disassembled to inspect cooling pipework and to repair any leaks. *(Note: the one small leak remaining has been established to be within the valve box and should therefore be accessible)*

BaBAR magnet refurbishment plan

- An engineering study and risk analysis in 2020 concluded that the "***magnet should be suitable for prolonged use as part of the detector system for the EIC project***."
- The study suggested the implementation of several proactive maintenance and improvement modifications.
- If the magnet continues to operate well throughout a high-field magnet test with the sPHENIX experiment, this refurbishment can be done without opening the cryostat.
- The scope of the reuse of the BaBar solenoid for Detector-1 includes a review by a panel of experts (following initial sPHENIX running), the disconnect of the magnet in IP-8 and move to IP-6, a new valve box, and assembly and magnet mapping in IP-6.

Need for a Replacement Magnet



Detector Solenoid Magnet Specifications

Parameter	Detector 1-Solenoid
Central Field (T)	1.5
Coil length (mm)	3512
Warm bore diameter (m)	2.84
Polarity	Bipolar
Lowest operating field (T)	0.5
Flat Field area	± 100 cm around center 80 cm radius
Field uniformity in Flat field Area (%)	8.5
RICH area	From z=+180 cm to 280 cm
Projectivity in RICH Area (mrad@30GeV/c) Projectivity in RICH Area (A/Tmm^2)	0.1 10
Stray field requirement	<0.5 mT @ z=-5.3 m, @z=+7.4 m, and @R=3.4 m
Cryostat length (m)	<3.85
Cryostat outer diamter (m)	<3.54
Charging voltage (V)	10
Fast discharge voltage maximum (V)	500
Quench hot spot temperature (K)	<150
Temperature margin (K)	>1.5
Current margin (%)	>30
Charging time (hr)	2-3
Cooldown time (weeks)	3-4
Cooling scheme	Thermosiphon
Conductor	Al Stabilized NbTi Rutherford Cable Cu Stabilized NbTi Rutheford Cable
Operating Temperature	4.5

} Topic of further study

Accelerator fringe field requirements, under further study. These may imply local shielding around IR magnets.

Magnet- Area of interest

The solenoid Field specification document is finalized . There are three areas of importance from the magnetic field point of view, these are:

- Flat Field Area
- RICH detector Area
- Stray field limitation at IR magnets and RCS

Flat Field Area: This are is 200 cm long and 80 cm in radius around the IP, the field uniformity required in this area is 8.5%

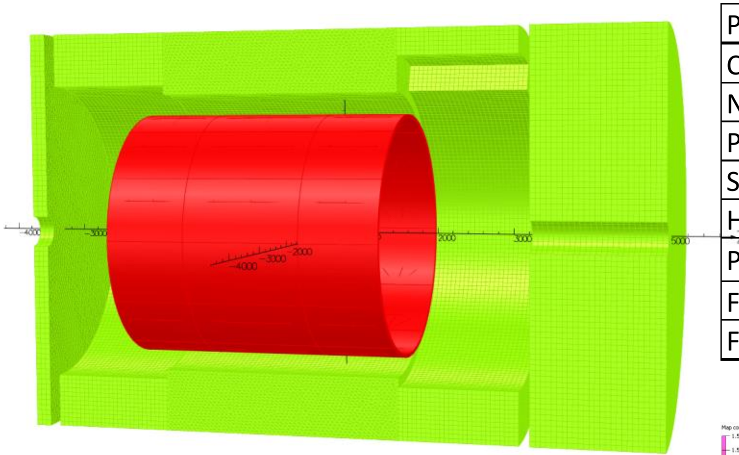
Stray Field:

The detector solenoid has neighboring IR magnets, in order to reduce the effect of solenoid magnet on IR magnets, there is a requirement of stray field less than 5G at B0ApF and Q1ApR magnets, these magnets extends from z= 7.4 m to 8 m and z=-5.3 m to -7.1 m respectively.

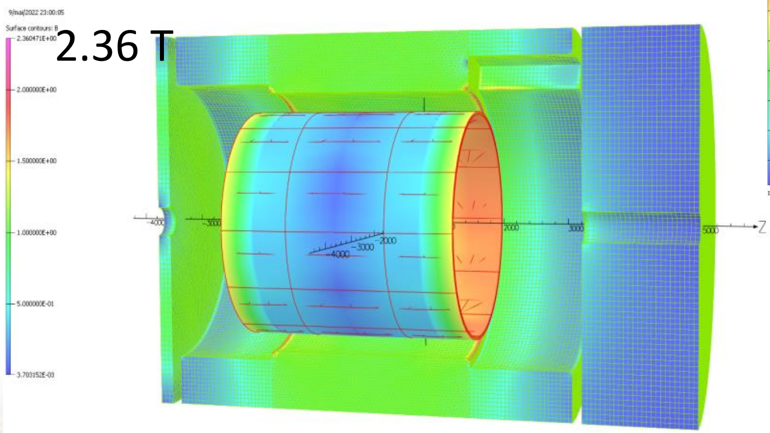
The RCS is radially 335.2 cm from the magnet central axis and stray field requirement there is <0.007 Tm

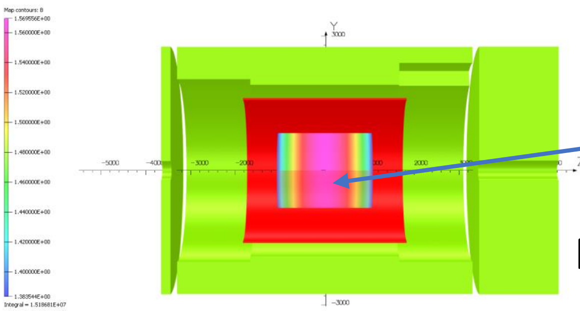
RICH detector Area: To maximize the RICH performance based on the gas radiator it is critical to minimize the bending of the tracks in the volume of the gas radiator. For this one needs to shape the field that it is parallel to the different scattering angles of particles covered by the RICH. The RICH area extends from z=+180 cm to +280 cm.

Detector-1 Existing Magnet- Design parameters



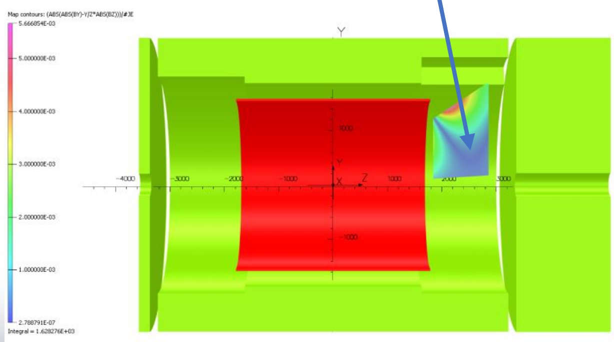
Parameter	Design Value	Specification	Unit
Central field	1.404	1.5	T
Nominal Current	4596		A
Peak field in the Coil	2.36		T
Stored Energy of the magnet	25.43		MJ
Homogeneity in the central region	2.2	8.5	%
Projectivity in RICH area	3.51	10	A/Tmm^2
Field at (0,0,-5.3 m)	35	5	G
Field at (0,0,7.4 m)	30	5	G



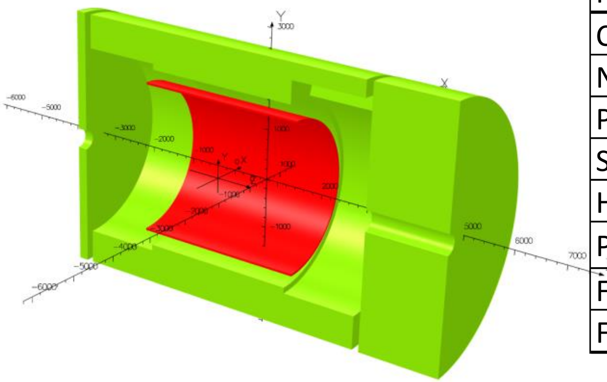


Homogeneity 2.2%

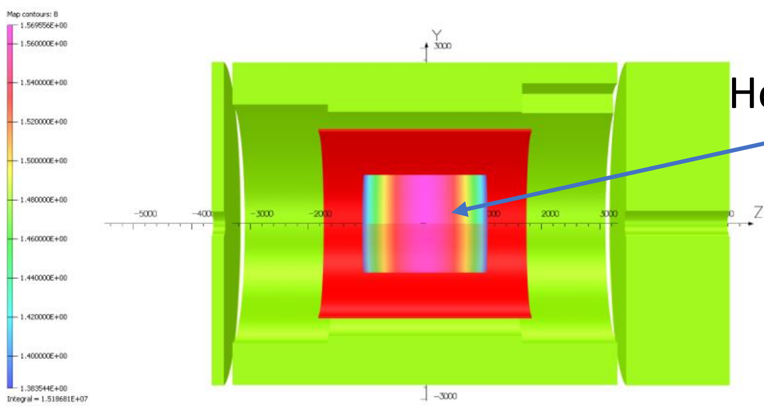
Projectivity 3.51 A/Tmm^2



Detector-1 New Magnet- Design parameters (Preliminary)

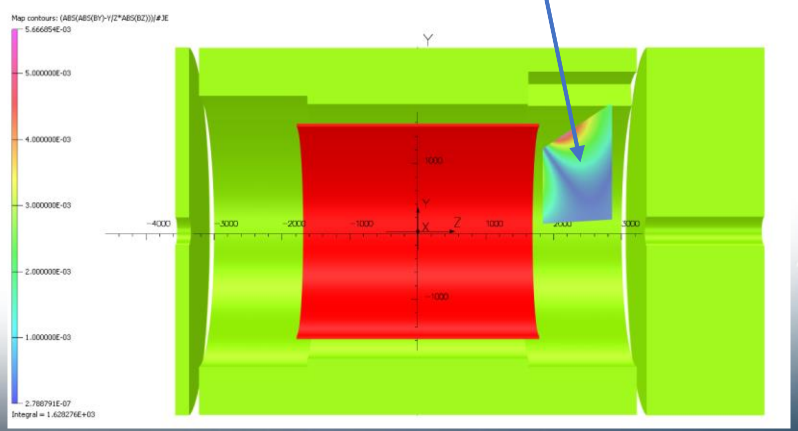


Parameter	Design Value	Specification	Unit
Central field	1.5	1.5	T
Nominal Current			A
Peak field in the Coil	2.2		T
Stored Energy of the magnet	25.254		MJ
Homogeneity in the central region	12.34	8.5	%
Projectivity in RICH area	1.63	10	A/Tmm^2
Field at (0,0,-5.3 m)	30	5	G
Field at (0,0,7.4 m)	20	5	G

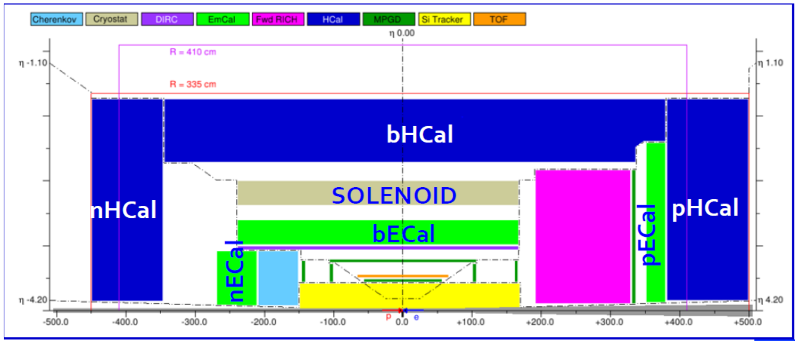


Homogeneity 12.3%

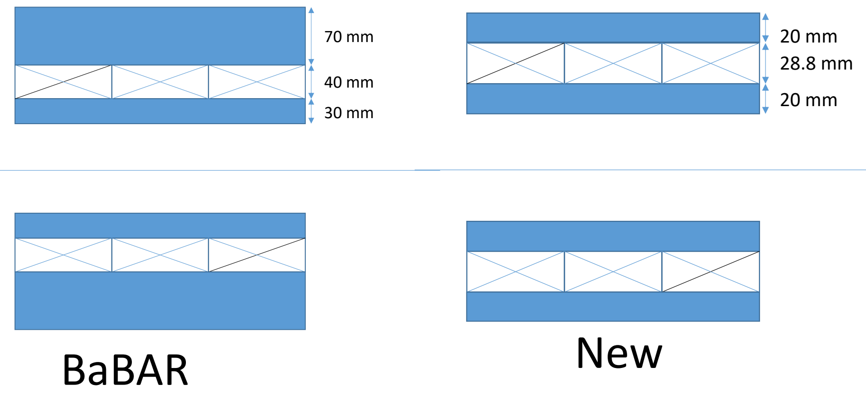
Projectivity 1.63 A/Tmm^2



Conductor- Al vs Cu choice



This picture of ATHENA detector, but concept is similar



Material (mm)	BaBAR	New
Al	36.72	0
Cu	1.72	25.6
NbTi	1.56	3.2
Support Al	100	0
Support SS	0	40
Total Al	136.72	0
Total Cu	1.72	25.6
Total SS	0	40
Total NbTi	1.56	3.2

0.42 interaction length in New
0.36 interaction length in BaBar
1.26 interaction length in SOCRATE

The materials in the EIC detector, including those in the solenoid, need to be consistent with the overall material budget that allows detection of relevant particles for EIC science, with their specific energies.

At the EIC, the barrel Hadron Calorimeter (bHCal) needs to act as tail catcher following the barrel Electromagnetic Calorimeter (bECal) that is ~ 1 λ_I (nuclear interaction length). This implies that the solenoid material needs to be “light” (~1.3 λ_I) to contain 95 % of the hadrons with energy of science interest in EIC.

Solenoid- Long Lead procurement

- The Detector solenoid is foreseen as a long-lead procurement item.
  - The detector solenoid is required to install all the detectors. The estimated installation time is 17 months.
  - The average time to procure a superconducting magnet from a vendor is approximately 5 years. This is based on experience with JLab-12GeV upgrade SC magnet procurement.
  - There are not many vendor for making this large size magnet nationally or internationally.
  - The conductor required for this magnet is also a long lead item. The conductor will be Al-cladded Rutherford cable and the Rutherford cable will be made with small SC strands.
  - The estimated time for Rutherford cable delivery is about 2 years, this is based on discussions with one vendor.
- The selected procurement strategy for the magnet is "Vendor Design-Build", we will provide a 'Performance Specification', reference design and a Statement of Work (SOW) to the vendor who then completes the design, produces their own manufacturing drawings and builds the magnet). In this option vendor has an option to validate and modify the design!
- In order to be ready for a long-lead procurement for the magnet at CD-2/3A, we need to complete the reference design, reference drawings and a SOW for the vendor by CD-2/3A.

Design of 1.5T Magnet

- The design will be divided in 60% and 90% design phase.
- Conductor R&D
- In parallel:
  - Continue monitoring sPHENIX magnet run
  - Update risk analysis based on the sPHENIX run.
  - Update the Risk analysis document
  - Review the results
  - Make a decision about the magnet choice (existing vs replacement new)
- Prepare document for RFQ

Design of 1.5 T Magnet (60% milestones)

- Complete 60% design including the following:
  - Complete conductor stability calculation (100%)
  - Finalize the conductor R&D plan (100%)
  - Start preparing conductor samples (after finalizing the vendor) (100%) ,
  - Preliminary quench calculation on the selected conductor (100%) ,
  - Finalize the conductor (100%)
  - Finalize power supply, current leads and quench protection scheme (100%)
  - Request for Information (RFI) to magnet and power supply vendors (100%)
  - Detailed electromagnetic Design (60%)
  - Detailed mechanical (60%)
  - Thermal Analysis (60%)
  - Quench Analysis (60%)
  - Cryogenic Design (30%)
  - I&C (10%)
  - System and sub-system drawings (60%)
  - Vendor search for conductor, magnet, power supply, current leads and other subsystems (60%)

Design of 1.5 T Magnet (90% milestones)

- Complete 90% design including the following:
  - Complete electromagnetic Design (90%)
  - Complete mechanical (90%)
  - Thermal Analysis (90%)
  - Quench Analysis (90%)
  - Cryogenic Design (90%)
    - Cryoflex line design (100%)
    - Cryocan design (100%)
  - I&C (90%)
  - System and sub-system drawings (90%)
  - Vendor search for conductor, magnet, power supply, current leads and other subsystems (100%)
  - Procurement reviews for all sub-systems
  - Complete RFQ documents

Magnet Procurement Options

There are typically four procurement approaches. Only two of these options (1 and 2) will be considered here for the detector solenoid:

1. **Build-to-Print** – Jlab-CEA produces a 90% design, a full set of manufacturing drawings and a Statement of Work (SOW). The vendor uses these drawings to build the magnet.
2. **Vendor Design-Build** – Jlab-CEA provides a 'Performance Specification', preliminary design and a Statement of Work (SOW) to the vendor who then completes the design, produces their own manufacturing drawings and builds the magnet.
3. **Design and Build at JLab** – Jlab-CEA produces the complete 90% design of the magnet, all the manufacturing drawings and builds the magnet.
   - This option is presently not considered to be realistic for the EIC project due to the lack of appropriate manufacturing facilities and manufacturing resources at JLab
4. **JLab 60% design + Vendor Design-Build** – Jlab-CEA produces a design to the 60% completion point, the vendor completes this design, produces manufacturing drawings and then builds the magnet.
   - This option is not presently being considered based on previous experience, not very successful implementations of this approach. When used in the recent past (2013 – 2017), vendors adopted one of two approaches when presented with a 60% design. They either;
     - Completed the design, apparently without due consideration for the manufacturability of the system, which then led to significant rework which in turn increased cost and extended schedules, or
     - Spent time reworking the design to ensure manufacturability, which also led to increased cost and extended schedules.
   - The fact that the vendors were working to a fixed-price contract meant that they were reluctant to increase their costs and this unfortunately led to reduced quality of components and build.

Option 2: It is like a 60% design, but giving the vendor an option to validate and modify the design!

Work with CEA and Task List

- CEA, Saclay is our collaborator for the design phase.
- The existing contract is for 60% design work,
- This work will be a collaborating work between JLab and CEA, Saclay.
- The following tasks will be complete and delivered at the end of 60% design
- Conductor stability calculations and conductor selection
  - This task will result in finalizing the conductor.
- Preliminary quench analysis
  - This task will result in a preliminary quench report. This will also help in finalizing the power supply including the current leads.
- Electromagnetic design (60%)
  - In this subcontract the following tasks will be completed for the electromagnetic design:
    - Magnet design fulfills all the physics requirements including the stray field requirement (if stray field requirement is not fulfilled, an agreement has to be reached with the accelerator group for the acceptable limits of the stray field)
    - The turns and layers layout are complete based on conductor dimensions
    - Magnet operating parameters finalized
    - Conductor length and possible piece size finalized
    - Winding technique discussed and if possible finalized
    - Magnetic forces calculated and given as input for the mechanical analysis

Work with CEA and task list-contd.

- Mechanical design (60%)
  - In this subcontract 3-d analysis will be done using ANSYS software, showing that the main mechanical parts and stress level in all the parts are within the design limit and system is in safe operational limits. In this subcontract the following tasks will be completed for the mechanical design:
    - Standard 3-d mechanical analysis using ANSYS
    - Stress analysis using the gravitational load, winding, electromagnetic and thermal loads
    - Make sure all the stresses are with-in the safe design and operating limits
    - Material selection for all the supports and vessels
    - Considered all thermal contractions and drawing adjusted to that
    - Winding tension to be used on the conductor
- Thermal Design (60%)
  - In this subcontract 3-d analysis will be done using ANSYS software, showing the temperature distribution in the cold mass and stress while cool down the system to liquid Helium temperature. In this contract following tasks will be completed for the thermal design:
    - Standard 3-d thermal analysis using ANSYS
    - Thermal distribution for the mechanical analysis
    - Thermal distribution for current and temperature margin
    - Thermal distribution across the whole cold mass
    - Decide about the rate of cooldown and warm up the cold mass
    - Stress during cooldown and warm up, any limit to set on these in the controls

Work with CEA and task list-contd.

- Quench Analysis (60%)
  - The final quench analysis will be done using the standard multi-physics equations and OPERA 3-d quench modeling. The quench analysis will take input from thermal analysis, electromagnetic design. In this subcontract the following tasks will be completed for the quench analysis:
    - Standard 3-d quench analysis in OPERA
    - Quench validation using standard multi-physics equations
    - Make sure all the temperatures in the event of quench are within the safe limits
    - Make sure that the magnet stored energy is dissipated in the safe manner in the event of quench
- Cryogenic design (30%)
  - In this subcontract preliminary 3-d analysis will be done using ANSYS software, this will include the 4-K circuit design, thermal shield design, vacuum vessel design. This will also include cryo-flex and cryocan design. In this subcontract, the following tasks will be completed for the cryogenic design:
    - Finalize the cooling scheme and cooling layout
    - Calculated all the heat loads
    - Input for thermal and mechanical design
    - Input for quench analysis
- Instrumentation and controls design (10%)
  - This will take input from all the above sub-system designs and make a list of all the instruments to be used in the system and how to control all of these. The following tasks will be done:
    - Prepare a list of all the instrumentation and control
    - Preliminary electrical drawing
    - Discussion with the project control person to plan the control strategy
- Components, sub-systems and system drawing (60%)

What Next

- Finalize the magnet specification.
- Update BaBAR magnet risk assessment.
- Complete 60% design including the following:
  - Complete conductor stability calculation, finalize the conductor R&D plan, start preparing conductor samples (after finalizing the vendor), preliminary quench calculation on the selected conductor, finalize the conductor.
  - Finalize power supply, current leads and quench protection scheme.
  - Complete the detailed electromagnetic, mechanical, thermal and cryogenic analysis of the magnet
  - Start working on I&C
  - Start working on the system and sub-system drawings
- Vendor search for conductor, magnet, power supply, current leads and other subsystems

Summary

- The design team is in place at JLab and CEA, Saclay
- Official contract is signed between two labs and we have started the design work.
- We have started looking at the existing magnet drawings and we are trying to get more details from those drawings. The new magnet has to fit in the same space.
- Our recommendation for the procurement strategy for the detector solenoid is “Vendor Design-Build”.
- Most of the sub-systems are long lead items and their procurement will be planned carefully.
- Conductor selection and procurement is crucial for the success of this project.
  - The conductor is a long lead item and needs to start before magnet procurement. For the “Vendor Design-Build” approach, the magnet vendor will be allowed to select the conductor to suit their design but will work with JLab-CEA to source the conductor.

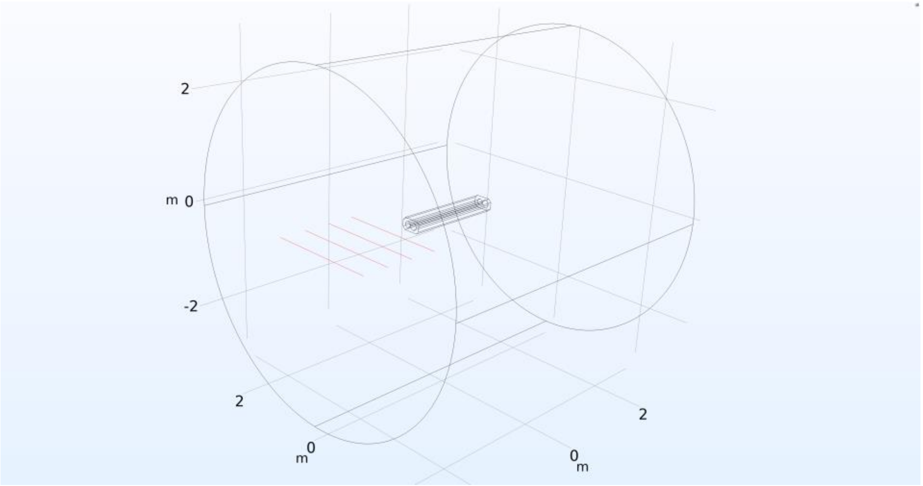
Back up Slides on Stray Field

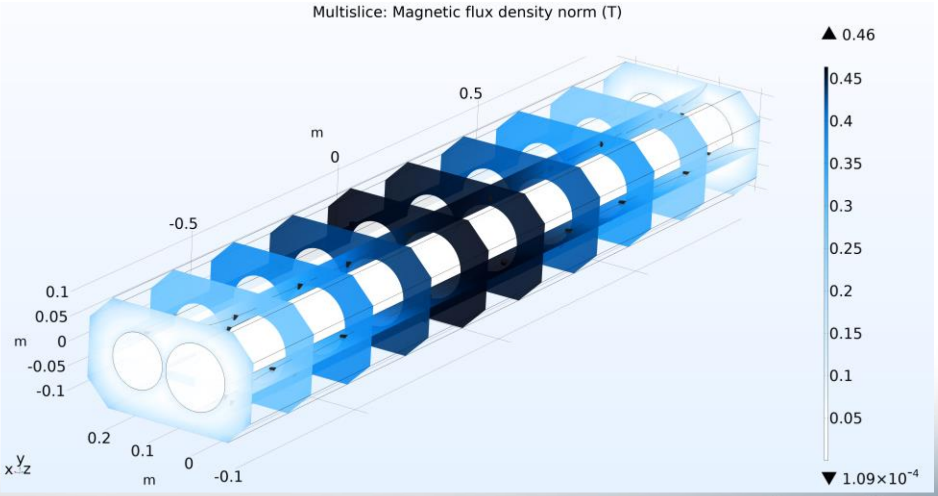
Fringe Field requirement-IR magnets

Stray field should be less than 5G (preliminary) at B0ApF and Q1ApR magnets, these are the closest magnet to the solenoid.

- 5G fringe field is not easy to achieve
- Simulation were done for the ECCE magnet, the simulations show that fringe field can be reduced to 10-15 G(Valerio's talk).
- Further simulation for ATHENA will be done in next phase

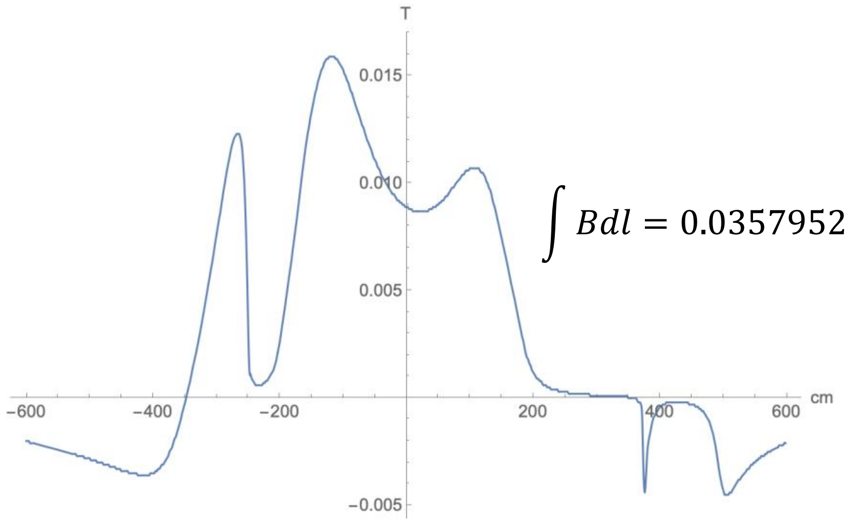
- Studies are being done to find the upper limit of fringe field with various background field on IR magnet yoke.
- 10mT background field gives 0.45 T field in the yoke (not acceptable)





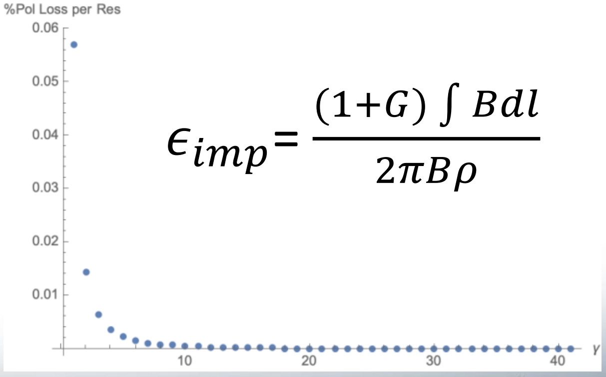
Fringe Field Requirement-RCS

The Rapid Cycling Synchrotron (RCS) relies on full symmetry around the ring that the electron polarization can be preserved at its maximum value.
Any significant fringe field will impact the spin precession and lead to loss of polarization



$$\int Bdl = 0.0357952\ Tm$$

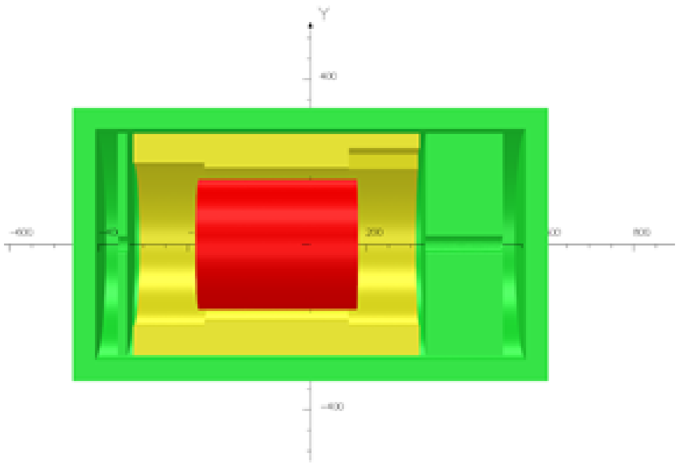
$\epsilon_{imp}(G\gamma = 1)$= 0.00387814 → loss of 5% at first Imperfection resonance, product of all crossings during 18 GeV ramp = 10% loss



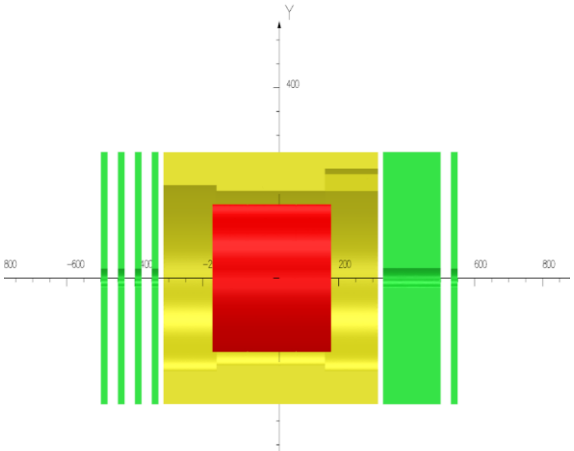
$$\epsilon_{imp} = \frac{(1+G)\int Bdl}{2\pi B\rho}$$

We Need shielding of the RCS beam pipe to bring fields down by a factor of 5 to bring cumulative loss < 1%

Stay Field Reduction study



Add an extra iron cylinder around the magnet



Add some extra iron plates in ± Z directions

Configuration	Field at z= -5.3 m (G)	Field at z=7.4 m (G)
ECCE configuration	35	30
ECCE configuration with extra steel cylinder around barrel	35	13
ECCE configuration with extra steel surrounding all around	18	10
ECCE configuration with extra steel plates in +z and -z direction	25	22