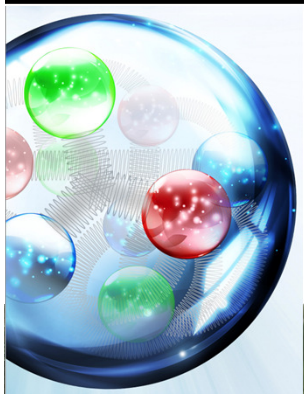
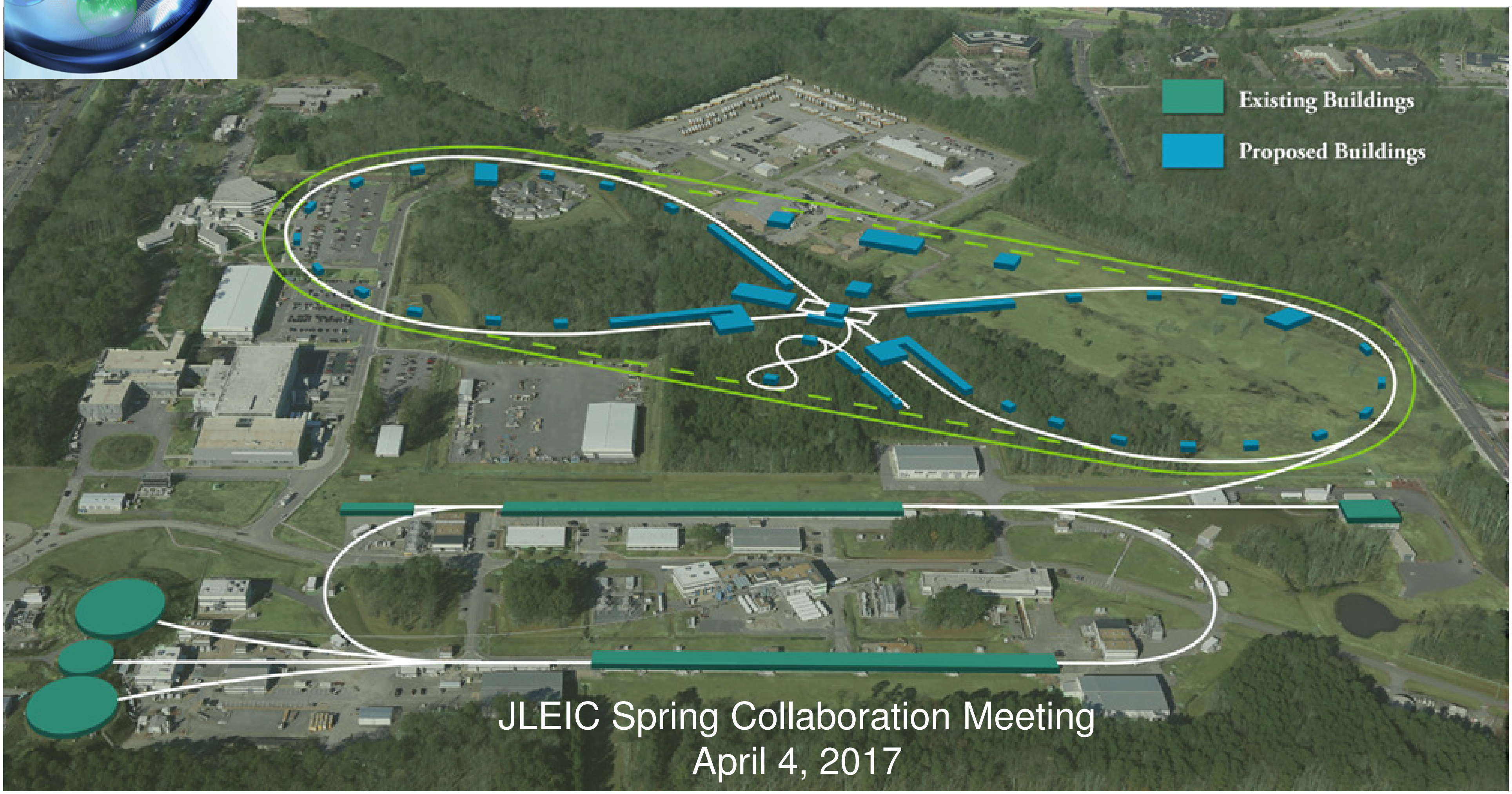


JLEIC Magnet R&D

Tim Michalski



JLEIC Spring Collaboration Meeting
April 4, 2017

JLEIC Magnet R&D

R&D Item	Priority	Initial TRL	Final TRL	Performance Period	Burdened Cost
MAG1 – S-F 3T Dipole Prototype for Fast Ramping Cold Mass Production and Test	First	Low	Med	2017-2018	$1,147k
MAG2 – Alternate Superconducting Magnet Design for Fast Ramping Collaboration with LBNL	Second	Med	Med	2017-2018	$ 904k
MAG 3 - Superconducting Full Length Prototype Magnet with Cryostat - Production and Test	Second	Med	High	2018-2021	$4,059k
MAG4 – IR Magnets R&D - Compact, Large Aperture, High Radiation	First	Low	Med	2017-2020	$4,203k
MAG5 – Cooler Solenoids for ERL Cooling	Third	Med	High	2019-2022	$3,047k(*)
MAG6 – Spin Rotator Solenoids for JLEIC Electron Collider Ring	Third	Med	High	2018-2021	$3,096k(*)

* - Burdened cost if electing to fabricate and test a first article solenoid segment

JLEIC Magnet R&D – Community Review Report

R&D Item	Priority	Initial TRL	Final TRL	Performance Period	Burdened Cost
MAG1 – S-F 3T Dipole Prototype for Fast Ramping Cold Mass Production and Test	**RCR-HIGH**	Low	Med	2017-2018	$1,147k
MAG2 – Alternate Superconducting Magnet Design for Fast Ramping Collaboration with LBNL	**RCR-LOW**	Med	Med	2017-2018	$ 904k
MAG 3 - Superconducting Full Length Prototype Magnet with Cryostat - Production and Test	**RCR-LOW**	Med	High	2018-2021	$4,059k
MAG4 – IR Magnets R&D - Compact, Large Aperture, High Radiation	**RCR-HIGH**	Low	Med	2017-2020	$4,203k
MAG5 – Cooler Solenoids for ERL Cooling	**RCR-LOW**	Med	High	2019-2022	$3,047k(*)
MAG6 – Spin Rotator Solenoids for JLEIC Electron Collider Ring	**RCR-LOW**	Med	High	2018-2021	$3,096k(*)

* - Burdened cost if electing to fabricate and test a first article solenoid segment

Ion Collider/Booster Ring Magnets

- Value Engineering of Ion Collider/Booster Ring Magnets
  - There are ***3 R&D activities focused towards the best value*** Ion Collider/Booster Ring arc magnets;

HIGH • *MAG1* – TAMU Super-ferric, 3T, Fast Ramp Prototype Cold Mass

LOW • *MAG2* – Alternate SC Magnet design for fast ramping

LOW • *MAG3* – Technology selection then prototype magnet with cryostat

  - Need to achieve ***3T dipole field*** and ***fast ramp*** (Booster Ring – 1T/sec for dipoles)
  - Texas A&M University's Accelerator Research Lab (TAMU) ***super-ferric (SF) magnets are a potential cost savings for JLEIC arc magnets***
  - ***Cos(θ) technology*** – "*Magnet requirements for the Booster are also within the range that has been demonstrated in the past, but mostly at the level of short prototypes built and tested in a Laboratory.*" ***Need to understand the limits on ramp rate.***

MAG1 - SF, 3T, Fast Ramping Dipole Magnet

- Initial TRL – TRL 2 (Low)
  - Completed:
    - Analysis of TAMU 1.2m SF dipole design using cable-in-conduit (CIC) conductor
    - Development and testing of prototype CIC conductor
    - Mock up winding by TAMU – analyzed field quality vs actual coil placement accuracy

MAG1 - SF, 3T, Fast Ramping Dipole Magnet

- This R&D activity will deliver:
  - Continuous length of ***CIC conductor to build 1.2m dipole***
  - Fabrication of a ***1.2m SF dipole cold mass*** – vacuum tube, coils, flux return steel, outer shell
  - Test cold mass in a test cryostat – ***Test of max field, field quality, ramping characteristics***
  - ***Validation of SF technology*** to meet JLEIC arc magnet requirements

- Final TRL – TRL 5 (Medium)
- Total Burdened Cost – $1,147k – includes TAMU's development cost of 1.2m SF dipole cold mass

MAG1 – Review Report Recommendations

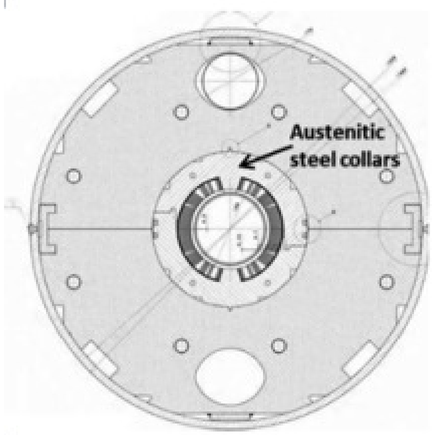
- ***A booster magnet study must be performed to validate the superferric technology*** with respect to the JLEIC arc magnet requirements.
- The panel recommends the ***fabrication of a 1.2 m superferric dipole cold mass, the coils and cryostats and the according vacuum chamber***.
- The ***high field quality relies on a high accuracy of the yoke geometry and a precise coil winding***.
- A ***prototype cold test and magnetic field measurements*** at different field level need to demonstrate the required field quality, the ramp rate and the quench performance.
- In addition, the prototype can provide ***a good basis to estimate the costs*** of the booster magnets.
- The JLAB collaboration with Texas A&M has been productive, but given the importance of the magnets to the JLEIC concept, ***JLAB should ensure that it develops appropriate in-house expertise to bolster this collaboration*** and to ***also consider alternative magnet designs***.

MAG2 - Alternate SC Magnet, Fast Ramping

- Initial TRL - TRL 5 (Medium)
  - Current Dominated ***(Cos(θ)) magnet technology is well understood*** with capability in the region of required field strength
  - The technology is the basis for most collider superconducting magnets
  - ***Fast ramping*** Cos(θ) magnets - ***many designed, a few built***
- Result from this R&D effort is a ***basis for Value Engineering Ion Collider/Booster Ring arc magnets*** (in conjunction with SF magnet R&D)

MAG2 - Alternate SC Magnet, Fast Ramping

Courtesy P. Fabbricatore - INFN



SUMMARY OF REQUIREMENTS AND CARACTERISTICS OF A SHORT SIS300 DIPOLE

Nominal Field (T) :	4.5
Ramp rate (T/s)	1
Radius of magnet geometrical curvature (m)	66,667
Magnetic Length (m)	3.879
Bending angle (deg)	3 1/3
Coil aperture (mm)	100
Total ac losses (W/m) during current ramp	<10
Block number	5
Turn number/Layer	34/1
Operating Current(A)	8920
Cod Mass Outer Radius (mm)	250
Peak Field (T)	4.9
Working point on load line	69%

Ac losses in the magnet body (no end coils contribution)	**SIS300 4.5T 100mm bore** Total loss when ramping from 1.5T to 4.5T at 1 T/s: **7.7 [W/m]**	
Hysteresis	30 %	$D_{fil\ effect}$ =3.5 µm (2.5 µm geom. 3 µm eff.)
Coupling Strand	9 %	CuMn ρ_t = 0.43 nΩ·m (0.3 nΩ·m) lp 5 mm (7 mm)
Interstrand Ra+Rc	6 %	Cored cable
Total conductor	**(45 %)**	
Collars + Yoke eddy + Prot. sheets	6 %	Collar 3 mm tick Iron 1 mm tick
Yoke magn	24%	H_c (A/m)=35
Beam pipe	14 %	$\frac{\pi}{\rho_0} \cdot \dot{B}_0^2 \cdot r_a^3 \cdot \Delta r$
Collar-Keys-Pins	8 %	
Yoke-Keys-Pins	3 %	

RHIC magnets known for their cost-effectiveness

RHIC magnets adapted for fast ramp? First versions of SIS300… → *M. N. Wilson et al. "Design studies on superconducting Cos(θ) magnets for a fast pulsed synchrotron," IEEE Trans. Appl. Supercond, vol. 12, no. 1, pp. 313–316, Mar. 2002.*

MAG2 - Alternate SC Magnet, Fast Ramping

- This R&D activity will deliver:
  - ***Optimized SC magnet parameters*** for Ion Collider/Booster Ring arc magnets
  - ***Conceptual design*** for Ion Collider/Booster Ring arc magnets with analysis of conductor ***for fast ramping***
  - Ion Collider/Booster Ring arc magnet ***cost analyses***
  - ***Value Engineering assessment of Cos(θ) magnet technology versus super-ferric*** magnet designs proposed by TAMU
- Final TRL – TRL 6 (Medium) – information required for arc magnet value engineering study and subsequent down select on technology
- Total Burdened Cost – $904k – including LBNL costs

MAG3 - SC Full Length Magnet with Cryostat

- Initial TRL – TRL 5 (Medium)
  - Prior to start, expect to have:
    - Tested TAMU SF dipole cold mass
    - Concept magnet design for Cos(θ) arc magnets
    - Value Engineering study assessing Cos(θ) versus SF performance and cost
    - Down select on magnet technology
  - ***Supporting technology is well understood***, in similar applications and environments – cryostat, pressure systems, magnet alignment system, cryogenic piping, and LHe recooler design
  - HTc magnet lead designs exist for high current applications

MAG3 - SC Full Length Magnet with Cryostat

- This R&D activity will deliver:
  - ***Full length SC arc magnet prototype with cryostat***, fabricated and tested
    - SF magnet prototype would require quadrupole, sextupole, splice
    - Cos(θ) prototype would require full cold mass
    - Common items – cryostat, magnet mount/alignment, cryogenic piping and interface, thermal shielding, electrical interface, insulation
- Final TRL – TRL 7 (High)
- Total Burdened Cost – $4,059k – including either TAMU quadrupole and sextupole fabrication costs or Cos(θ) cold mass, in addition to common items

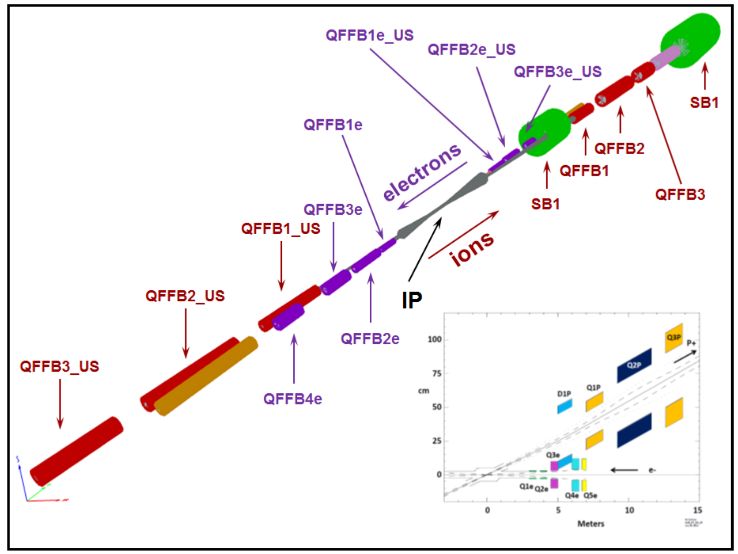
MAG2/MAG3 – Review Report Recommendations

- To reach the final center of mass collision energy of 100 GeV, dipoles with ***a field strength of 6 T in the collider are required to reach the 200 GeV proton energy***.
- As the collider requires a ramp rate of 0.1 T/sec only, the ***magnet design can follow LHC magnet design***.
- However, the panel recommends the ***exploration of 6 T superferric magnet as value engineering option***.
- The 3 T ***superferric magnets*** require experimental validation through prototyping and the ***extrapolation to 6 T is a high-risk item***.
- A ***full-length magnet prototype*** proposed ***is low priority*** R&D.

MAG4 - IR Magnets

- Initial TRL – TRL 3 (Low)
  - Magnets flanking the Interaction Region are challenged by:
    - High field strength/gradient requirements
    - Large apertures for large acceptance
    - 50 mrad crossing angle and proximity of beamlines to one another
    - High heat load and radiation effects from Synchrotron Radiation (SR)
    - Effects of fringe fields of adjacent magnets, including the solenoid

Name	Type	Length (m)	Good-field radius (cm)	Inner radius (cm)	Outer radius (cm)	Min. beam separation (cm)	Strength (T/m)	Pole-tip field (T)
QFFB1 (ion)	Quad (T/m)	1.2	4	6.8	17.1	35.9	-87	-6
QFFB2 (ion)	Quad (T/m)	2.4	4	11.8	24.7	48.2	50	6
SB1 (ion)	Dipole (T)	1.5	4	17	24	25.0	-1.3	-1.3
QFFB1e (electron)	Quad	0.4	1.2	2	6	8	24.4	0.49
QFFB2e (electron)	Quad	0.7	2	3	8	10.5	-57.7	-1.73



MAG4 - IR Magnets

- ***Magnet parameters have been defined*** for the Interaction Region (IR)
- ***The ARL at Texas A&M University has prepared conceptual designs for three of the most challenging magnets***:
  - A large-aperture high-gradient quadrupole for the innermost lens on the ion beam – QFFB1
  - A large-aperture dipole that must serve as a spectrometer for forward-going particles near the ion direction – SB1
  - A high-gradient, modest-aperture superconducting quadrupole that can operate with high gradient uniformity over large dynamic range – QFFB2e

MAG4 - IR Magnets

- This R&D activity will deliver:
  - Assessment considering magnet conductor selection and accelerator parameters – ***best valued design solutions while supporting performance and reliability objectives***
    - Magnet designs using NbTi conductor
    - Magnet designs using Nb3Sn conductor
    - Analyses to confirm that the resulting IR magnet requirements can be met (field, field quality, space constraints etc.)
    - Designs of IR magnets to meet design requirements (magnet, mechanical, quench protection, thermal and radiation load)
  - Fabrication of key IR magnet prototype(s)
  - Test in relevant environment

- Final TRL – TRL 6 (Medium)
- Total Burdened Cost – $4,203k – including TAMU, LBNL, prototype, and test costs

MAG4 – Review Report Recommendations

- ***Develop IR large aperture, high gradient quadrupoles and IR high field dipoles*** that correspond to a beam center of mass energy which can be extended to 100 GeV.
- ***Consider alternative, better-established magnet technology*** for IR large aperture quadrupoles of high gradients and IR dipoles of high fields for beam center-of-mass energy range from 20 to 100 GeV.
- The panel recommends to ***prototype the critical magnets that flank the IR in the JLEIC design***. These are the final focusing quadrupoles in the ion beam line. Because of the combination of high field and large aperture the coil field is at the limit or above what can be achieved with conventional NbTi technology.
- In addition, the proximity of the electron beam limits the available space and requires a very compact mechanical and flux return structure. The dipoles in the ion beam line have a large aperture. The proximity to the electron beam requires the effective suppression of the fringe field in that area and high radiation resistance.
- The SC magnet R&D for JLEIC can profit from ***collaboration with DOE laboratories that have strong expertise in this type of magnet technology***.

MAG5/6 - Cooling and Spin Rotator Solenoids

- Initial TRL - TRL 4 (Medium)
  - MAG5 – Cooling Solenoid – Required field quality and segmenting due to 30m length – 1T field
  - MAG6 – Spin Rotator Solenoid – Required field quality, impact of adjacent magnets and equipment, high integrated field in one version (may require SC conductor alternate to NbTi)
  - ***Superconducting solenoid magnet technology is well understood***
  - Methods to address solutions to the presented design challenges exist, such as shield coils, supplemental end coils, and the like
  - Divide into multiple segments while maintaining the overall ∫BdL
- This R&D activity will deliver:
  - ***Engineering design of solenoid magnet segment*** – TOSCA models, field quality definition, study of interaction with surroundings, and shielding
  - If warranted, fabricate and test solenoid first article segment(s)
- Value Engineering of solenoid segments to design for quantity builds
  - Cooling - 2 x 30m – quantity 10 x 6m segments
  - Spin Rotator – 2 x 2.5m and 2 x 5m

- Final TRL – TRL 7 (High)
- Cooling Solenoid Total Burdened Cost – $3,047k, including first article segment

  $ 930k, without first article
- Spin Rotator Solenoid Total Burdened Cost – $3,096k, including first article segment

  $ 980k, without first article

MAG5/6 – Review Report Recommendations

Row No.	Proponent	Concept / Proponent Identifier	Title of R&D Element	Panel Priority	Panel Sub-Priority
69	JLAB	INJ5	Ion sources	Low	
70	JLAB	IRS3	Collimation and machine protection	Low	
71	JLAB	MAG2	Alternate SC 3T fast ramping magnets	Low	
72	JLAB	MAG3	Full length prototype magnet and cryostat	Low	
73	JLAB	MAG5	Cooler solenoids	Low	
74	JLAB	MAG6	Spin rotator solenoids	Low	
75	JLAB	SRF3	Universal modular cryomodule	Low	

Table 1: Prioritized List of Proposed R&D Activities.

Summary

- Ion Collider/Booster arc magnet technology R&D is underway - Additional **R&D is required** to:
  - ***Validate super-ferric technology*** to achieve JLEIC requirements
  - Perform ***Value Engineering*** of ion arc magnets
- ***IR Magnet R&D is warranted*** to address technical and implementation challenges
- JLEIC solenoid magnet requirements appear within existing technology performance ranges – need to confirm there are no hidden performance limitations

- ***Overall Review Report Recommendations match the initial presentation summary quite well.***