Accelerator R&D in the DOE Office of Nuclear Physics

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DOE Office of Nuclear Physics

EIC User Group Meeting 2018
The Catholic University of America
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DOE Office of Science Accelerator R&D Categories

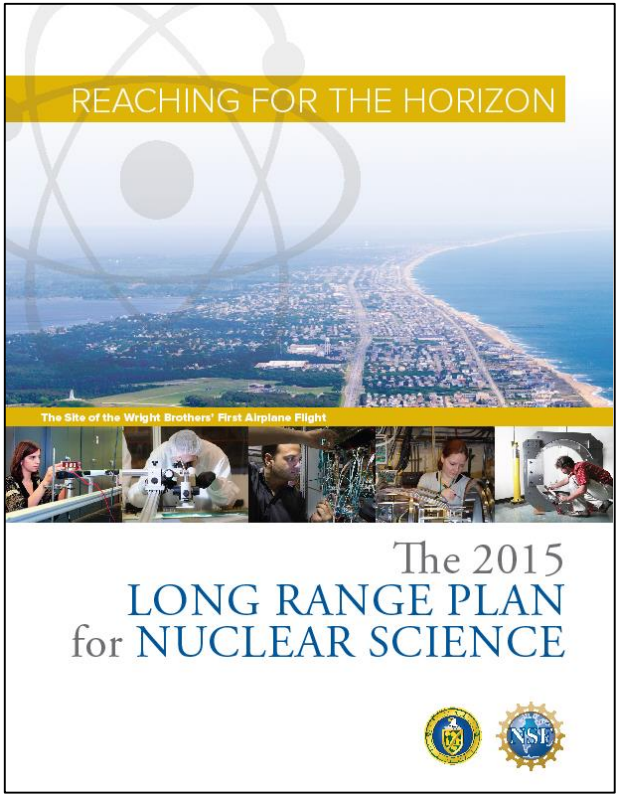
- **Short Term Accelerator R&D-** Accelerator R&D with the potential for improved performance and/or new capabilities to existing NP scientific user facilities that will lead to new capabilities or improved operations. This is supported by NP and other program offices.

- **Mid-Term Accelerator R&D**: Accelerator R&D with the potential for the development of the future generation of NP accelerators not under construction. This is supported by NP and other program offices.

- **Long-Term or generic Accelerator R&D**: This is directly supported by the Office of High Energy Physics (HEP) although NP work often relevant.

➢ Total annual direct NP investment in EIC-related accelerator R&D through competitive funding opportunity announcement (FOA) and National Laboratory Accelerator R&D is on the order of $13.5 M per year and increasing.

2015 NSAC LRP Report



RECOMMENDATION III (Page 4)

Gluons, the carriers of the strong force, bind ……

We recommend a high-energy high-luminosity polarized EIC as the highest priority for new facility construction following the completion of FRIB.

INITIATIVES : (Page 5)

B: *Initiative for Detector and Accelerator Research and Development*

……

We recommend vigorous detector and accelerator R&D in support of the neutrinoless double beta decay program ***and the EIC.***

The **key EIC machine parameters** identified in the LRP were:

- Polarized (~70%) electrons, protons, and light nuclei,
- Ion beams from deuterons to the heaviest stable nuclei,
- Variable center of mass energies ~20-100 GeV, upgradable to ~140 GeV,
- High collision luminosity ~10^{33}-10^{34} $cm^{-2}sec^{-1}$, and
- Possibly have more than one interaction region.

Planning towards an EIC

2015 LRP Recommendation III: "We recommend a high-energy high-luminosity polarized EIC as the highest priority for new facility construction following the completion of FRIB."

In view of this recommendation on the realization of an EIC, NP developed a near-term plan in discussion with EIC stakeholders:

- A science assessment of a US-based EIC by National Academy of Sciences
- A major NP Community EIC Accelerator R&D Panel Review
- A mechanism for increased accelerator R&D funding for FY17 and beyond

Planning Towards an EIC

- **National Academy of Sciences (NAS) Study:** Initiated an 18 month NAS study entitled: *"US-BASED ELECTRON ION COLLIDER SCIENCE ASSESSMENT"* Started in July 2016. **(Report completed)**

- **FY16 FOA:** Published competitive FOA ("Accelerator R&D for Next Generation NP Facilities") focused on EIC-related R&D. NP has been funding competitive accelerator R&D since 2010 at ~$2M/year.

- **NP Community Panel Review:** Conducted NP community EIC R&D panel review charged with identifying high priority R&D aimed at technical risk reduction. Dr. Kevin Jones of SNS chaired this international panel. First face-to-face meeting was held November 29-December 2, 2016. Panel Report published in February 2017 (https://science.energy.gov/np/community-resources/reports/)

- **FY17:** EIC-related Accelerator R&D plans received from Labs and universities and high priority R&D in the context of Jones report is supported.

- **Bi-Annual FOA starting FY18:** Published bi-annual FOA for competitive accelerator R&D based on R&D priorities established in the EIC panel report. **(Awards selected for FY 18)**
  - **Funding level**: ~$8.8 M per year for FY18 and FY19.
  - **Funding sources:** Combination of NP competitive accelerator R&D funds augmented with RHIC and CEBAF Accelerator Operations budget funding.

EIC Concepts

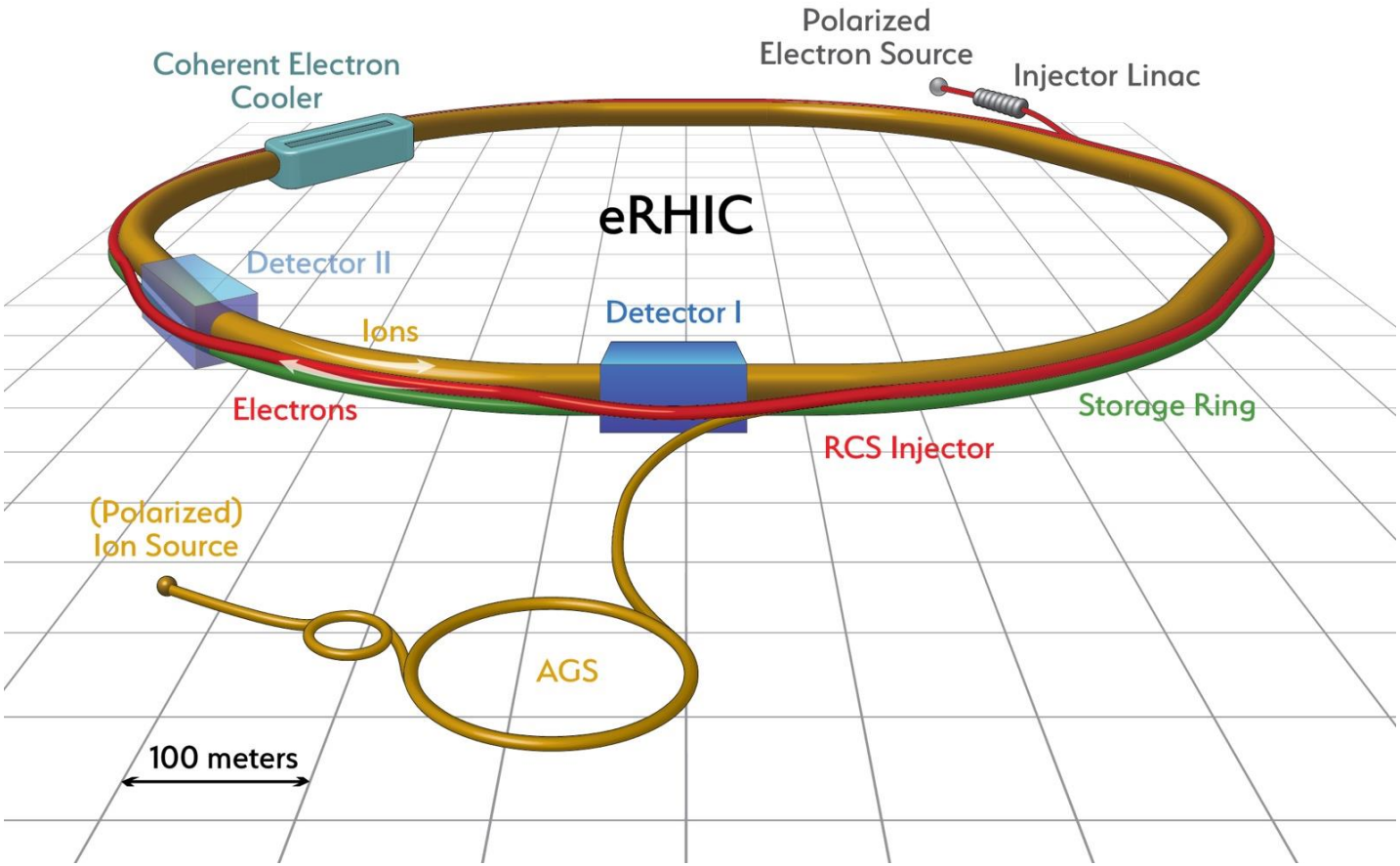
Current EIC concepts have emerged from national labs.

Strong collaborations at the labs and with universities to advance different concepts and common R&D relevant to all concepts:

- **BNL:** eRHIC based on a Ring-Ring concept
- **TNJAF:** JLEIC based on a high repetition rate figure-8 Ring-Ring concept

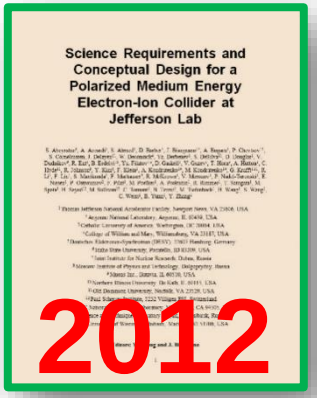
Note: At the time of the Jones panel review, BNL developing two different eRHIC concepts R-R and L-R. In April 2017, after the Jones report was published, BNL announced the R-R as the primary concept for eRHIC.

eRHIC Ring-Ring Design



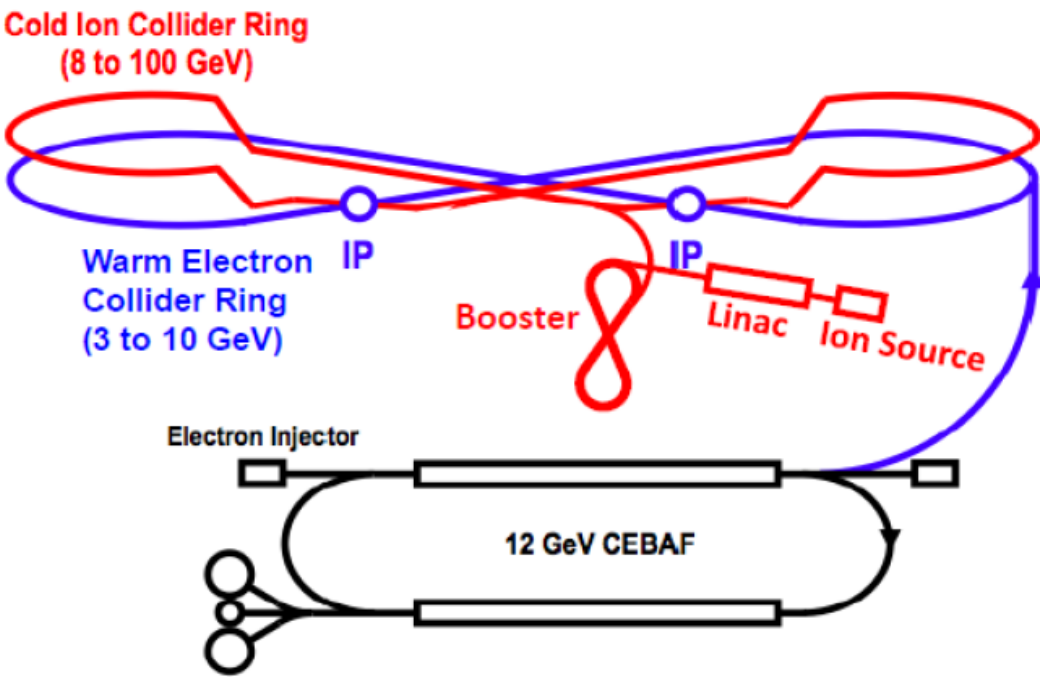
Storage ring for electron inside the RHIC tunnel

JLEIC Figure 8

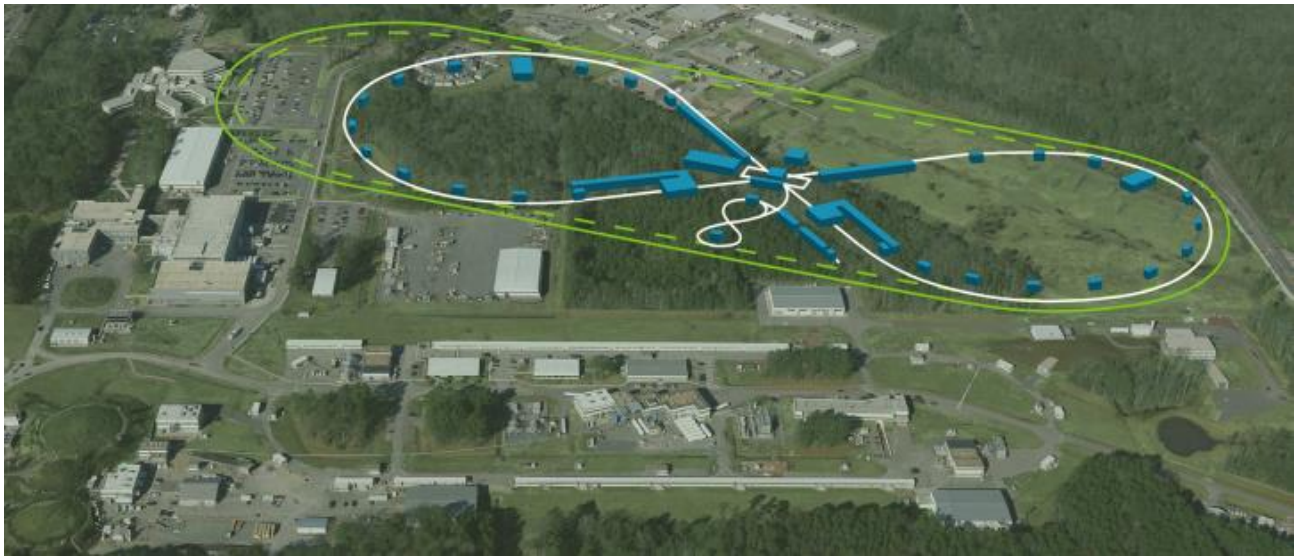


arXiv:1209.0757

arXiv:1504.07961



CEBAF is a full energy injector.



Jones Panel Priority Table:

Report of the Community Review of EIC Accelerator R&D for the Office of Nuclear Physics

February 13, 2017

2017

The **key EIC machine parameters** identified in the LRP were:

- Polarized (~70%) electrons, protons, and light nuclei,
- Ion beams from deuterons to the heaviest stable nuclei,
- Variable center of mass energies ~20-100 GeV, upgradable to ~140 GeV,
- High collision luminosity ~10^{33}-10^{34} $cm^{-2}sec^{-1}$, and
- Possibly have more than one interaction region.

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Jones Report R&D Priorities

Priority: "High", "Medium", or "Low", Sub-Priority: "A", "B", "C" or "None"
Proponent: "PANEL", "BNL" or "JLAB"
Design Concept: "RR", "LR" or "JLEIC"

- Sub-Priority-A: The R&D elements that the panel judged to be applicable to **all** concepts presented are identified by "ALL" in the concept/proponent identifier column and are assigned sub-priority A. **These are considered the most important to be addressed to reduce overall design risk.**
- Sub-Priority-B: The R&D elements that the panel judged to be applicable to individual concepts presented are identified by the appropriate concept identifier in the concept/proponent identifier column (e.g., LR, RR or JLEIC) and are assigned sub-priority B. **These are considered to be second in importance to reduce overall design risk, but important to reduce the risk associated with a specific concept.**
- Sub-Priority-C: The R&D elements self-identified by the proponents are tabulated in lines 23-75 with the priority as deemed by the panel. Specific self-identified high priority R&D elements that have substantial correlation with the high priority global and concept-specific sub-priority A and B elements identified by the panel are denoted as sub-priority C to permit ready cross-reference when evaluating future R&D proposals.

Technical Challenges for EIC

<u>EIC will be one of the most complex collider accelerators ever to be built.</u> It will push the envelope in many fronts including high degrees of beam polarizations, high luminosity, beam cooling, beam dynamics, crab cavities for both beams, and an interaction region with complex magnets.

Required Accelerator R&D Advances for EIC (list from the Jones panel report)

- Hadron cooling techniques
- Polarized electron sources
- Ring magnet demonstrations
- Interaction region magnet design and prototyping
- Machine-detector interfaces
- Superconducting RF technology
- Large scale cryogenics technology
- High current ERL linacs
- Crab cavity design, fabrication and testing (with beam)
- Beam and spin dynamics and benchmarking of simulation tools
- Electron cloud mitigation techniques

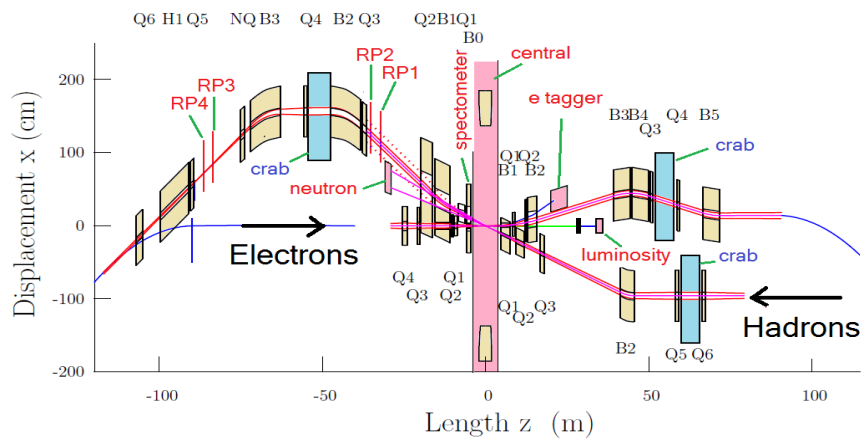
State of the Art Accelerator Technology for EIC

- **Beam Cooling:** Beam cooling is one of the highest priority R&D for EIC. The challenge is to achieve the high collision luminosity of order ~10^{33}-10^{34} $cm^{-2}sec^{-1}$.
  - High current multi-pass energy Recovery Linac (ERL)
  - High current unpolarized electron injectors for ERL
- **Interaction Region**
  - **Magnets:** Challenging magnet designs to meet required high fields and field free regions for passage of primary beams.
  - **Crab cavities:** Achieve maximized collision rates between bunches. No operational experience yet exists for crab cavities in hadron beams.
- **Storage ring Magnets**: Challenging high field storage ring magnets are needed.
- **Polarized electron Sources**: **H**igh bunch charges for the ring-ring concept
- **Simulation Codes:** Benchmarking of realist EIC simulation tools against available data needs to be aggressively pursued.

Core competencies in these areas exist at NP and SC Labs and universities. Collaborations have formed to address these technical challenges.

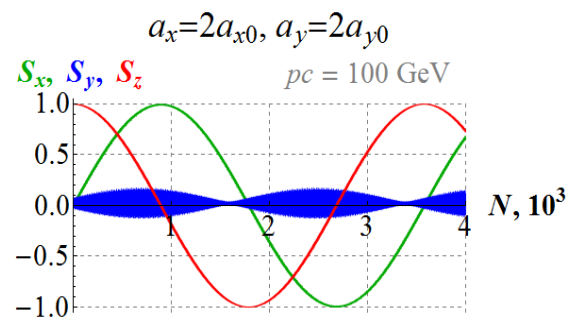
State of the Art Accelerator Technology for EIC

Schematic layout of IR



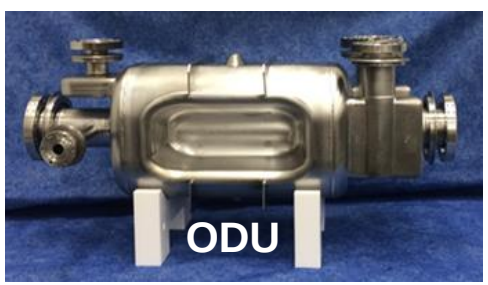
V. Ptitsyn *et al.*

Spin: Nonlinearity of orbital motion-



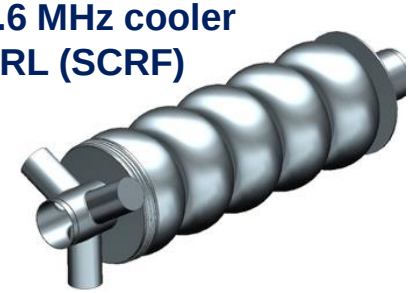
V. Morozov *et al.*

Crab Cavity



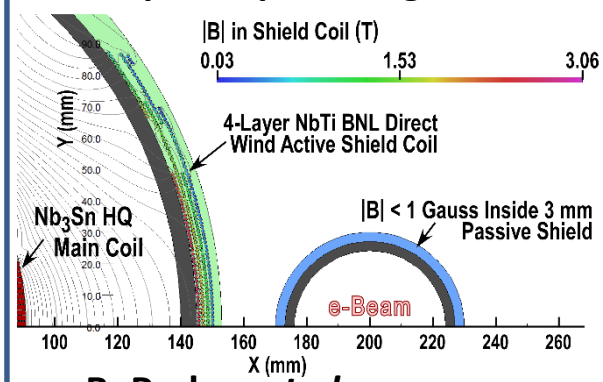
S. De Silva *et. Al*

952.6 MHz cooler ERL (SCRF)



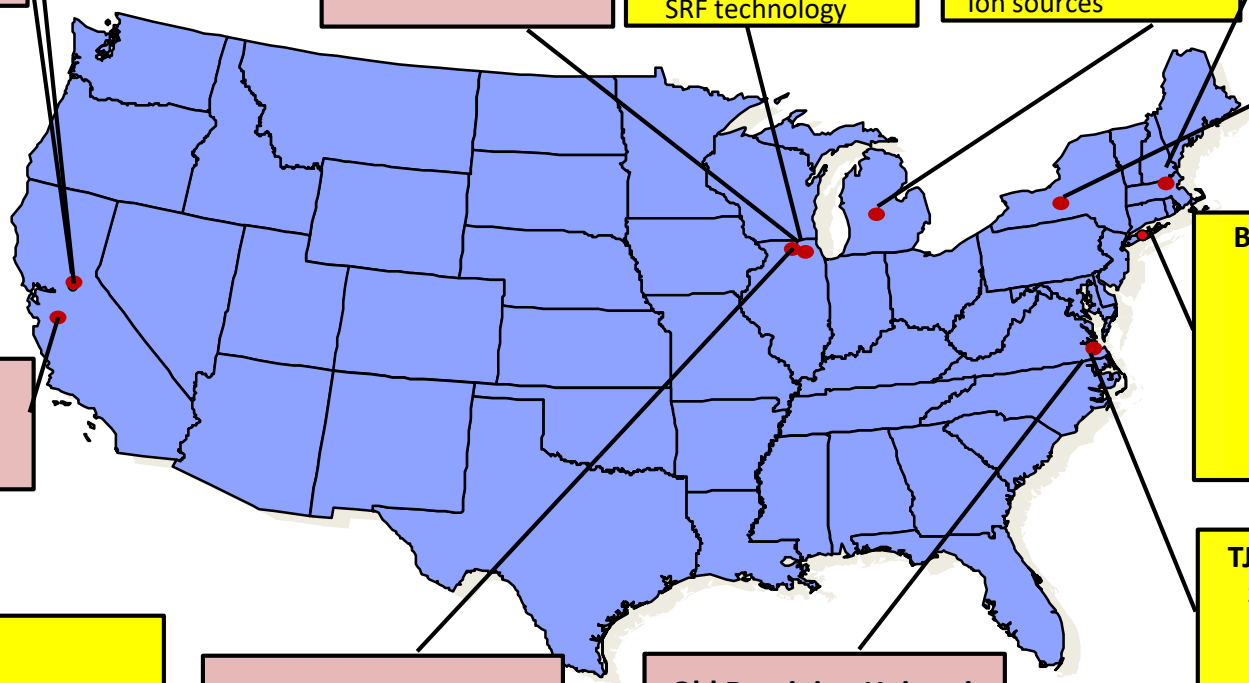
B. Rimmer, *et al.*

IR quadrupole magnet



B. Parker, *et al.*

Core Competencies for EIC at NP Labs and Universities



LBNL
Next Gen. ion source

LBNL
Beam simulation

FNAL
Beam Cooling

ANL
Beam simulation
SRF technology

Michigan State Univ. (FRIB)
SRF technology
Ion sources

MIT
High current polarized electron sources
Polarized He^3 source

Cornell University
High current e. sources
SRF technology

BNL (RHIC)
Beam cooling
Crab Cavity design
Beam simulations
Colliders
Polarized ion sources
SC magnet design

SLAC
Beam simulation

TJNAF
SRF technology
ERL
Polarized electron sources
Beam simulations
SC magnet design

Northern IL University
Beam simulation

Old Dominion University
Crab cavity design

NP core competency

With NP EIC awards

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FY2017 R&D Plan Awards

Page 1			FY 2017 EIC R&D Plan Awards	
Proposal ID	**Institution**	**R&D Area**	**Proposal Title**	**Principal Investigator**
232006	Cornell	Polarized e Source	Next generation robust pol. photocathodes for EIC	Ivan Bazarov
FY17 Add Collab. BNL	MIT/subc		High Current, High Charge Polarized Electron Sources	Bob Redwine /Evgeni Sentalovich
FY17 Additional	BNL		complete procurement of components for inverted gun	John Skaritka
FY17 Base	BNL		Gatling gun, laser system and design of new inverted gun	John Skaritka
FY17 Additional BNL	BNL	Polarized 3He Source	Development of a Polarized 3He Ion Source for RHIC	Anatoly Zelenski
FY17 Add Collab. BNL	MIT/subc		Development of a Polarized 3He Ion Source for RHIC	Richard Milner
FY17 Base	TJNAF	Beam Cooling	Magnetized Electron Source	Riad Suleiman
FY17 R&D	TJNAF		Electron Cooling Simulation Development	Yves Roblin
FY17 Base	BNL		Coherent Electron Cooling PoP experiment	Vladimir Litvinenko
FY17 Base	TJNAF		Electron Cooler Design	Steve Benson
FY17 Base	TJNAF		Bunched Beam Electron Cooling Experiment	Yuhong Zhang
232015	NIU		Studies of Conventional and ERL-Based Re-circulator Electron Cooling for an Electron Ion Collider	Bela Erdelyi
FY17 Add Collab. BNL	FNAL	Spin Dynamics	Study of Electron Spin Polarization in the EIC	Eliana Gianfelice-Wendt
FY17 Additional BNL	BNL		Study of Electron Spin Polarization in the EIC	Mike Blaskiewicz
FY17 Base	TJNAF		Spin Tracking in Ion and Electron Rings	Vasiliy Morozov
FY17 R&D	TJNAF	Magnet R&D	IR FFQ Prototype Definition	Tim Michalski
FY17 Additional BNL	BNL		Design and Prototyping of SC EIC – IR Magnets	Peter Wanderer
FY17 Base	TJNAF		Interaction Region (IR) Magnet Design Verification	Tim Michalski
FY17 R&D	TAMU/Subc		Complete and Test a Full Scale Suitable Superferric Magnet	Peter McIntyre/Tim Michalski

FY2017 R&D Plan Awards

Page 2			FY 2017 EIC R&D Plan Awards	
Proposal ID	**Institution**	**R&D Area**	**Proposal Title**	**Prinicipal Investigator**
113	ANL	Beam Dynamics	Beam Simulation and Benchmarking	Brahim Mustapha
FY17 Base	BNL		Beam-Beam Effects, Collective Effects Study, Dynamic Aperture	Mike Blaskiewicz
FY17 Base	BNL		eRHIC Electron Storage Ring Concept Development	Christoph Montag
FY17 Base	TJNAF		Beam-Beam Dynamics with Gear Changing	Yves Roblin
FY17 R&D	TJNAF	SRF R&D	Fast Feedback System and Kicker Design	Bob Rimmer
FY17 R&D	TJNAF		Test of CEBAF Electron Injection Mode	Jiquan Guo
111	ANL		ANL Plan for EIC R&D: HOM damping	Michael Kelly
FY17 Base	BNL		Design of state of the art RF systems for eRHIC	Kevin Smith
FY17 Base	TJNAF		Development of SRF Systems for an EIC	Bob Rimmer

- Areas of R&D: Mostly included highest rated R&D priority areas identified in the Jones panel report. Also included few areas TJNAF and BNL were doing R&D prior to the Community report.
- A two day Principal Investigator meeting is organized for November 13-14, 2018 for all PIs listed above to present their work to NP and other PIs to promote communication and collaboration amongst national labs and universities.

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Proposals submitted to FY 2018 FOA

Institutions	Number of Proposals	Budget Request Y-1 ($k)	Budget Request y1+y2 ($k)
National Labs	43	17,526	34,481
Universities	12	3,966	7,931
Industry	1	107	213
Totals	**56**	**21,599**	**42,625**

Collaboration Proposals

Type of Proposals	No. of Proposals	Total Individual proposals
Collaborative	16	43
Non-collaborative	13	13
Totals	**29**	**56**

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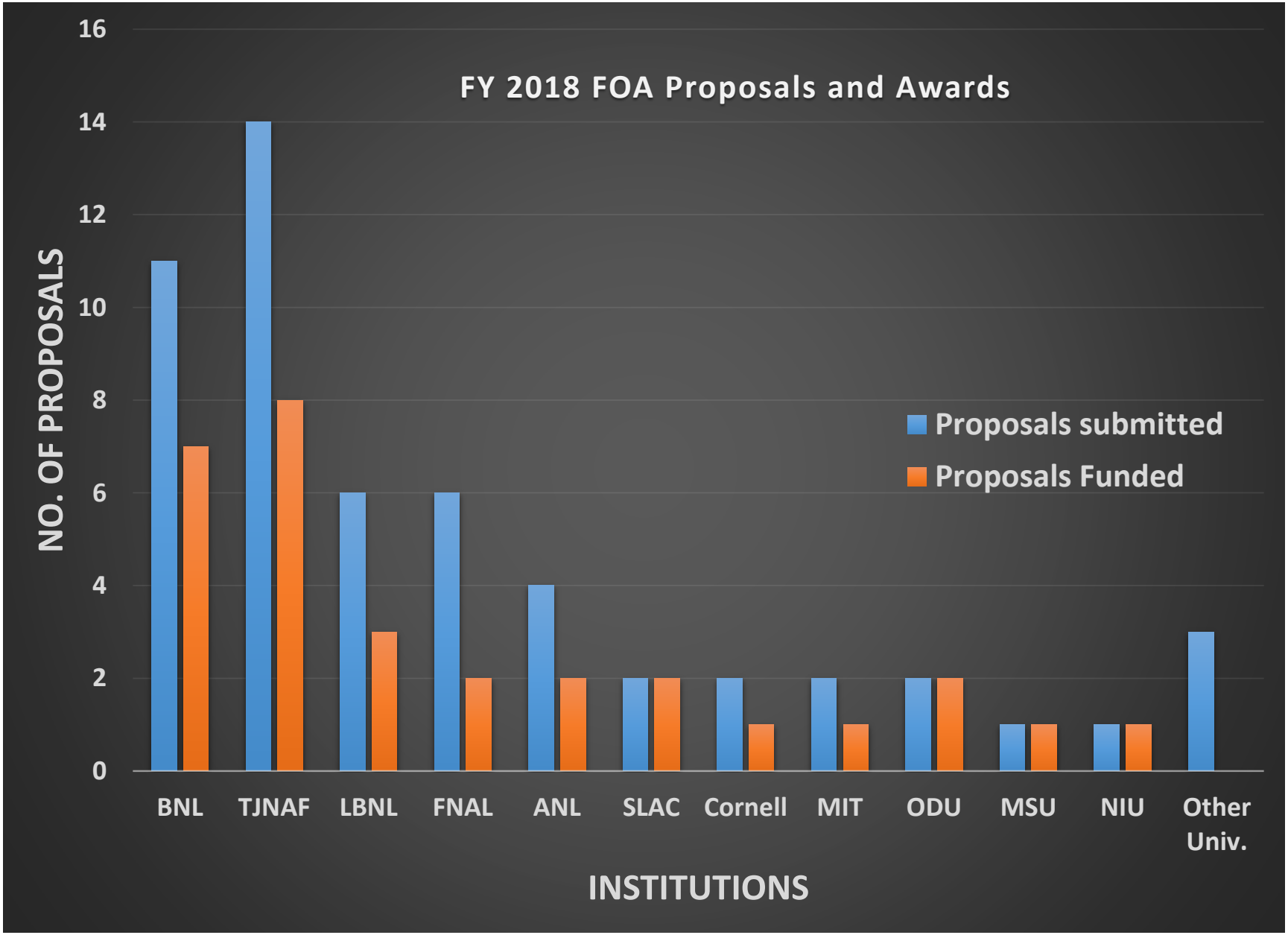

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List of FY2018 FOA Awards

Page 1

Proposal ID	Institution	Collab. num.	Proposal Title	PI
235278	FNAL		Ring-based high-energy electron cooler	Nagaitsev, Sergei
235263	BNL	Lead	Development and test of simulation tools for EIC beam	Luo, Yun
235254	LBNL		Collaboration	Qiang, Ji
235377	MSU		Collaboration	Hao, Yue
235315	TJNAF		Collaboration	Roblin, Yves
235309	TJNAF	Lead	Theoretical and experimental study of spin transparenc	Morozov, Vasiliy
235264	BNL		Figure-8 Ring (Collaboration)	Huang, Haixin
235325	TJNAF	Lead	Validation of EIC IR Magnet Parameters and Requirements Using Existing Magnet Results	Michalski, Timothy
235265	LBNL		Collaboration	Sabbi, GianLuca
235344	SLAC		Collaboration	Sullivan, Michael
235374	ODU	Lead	Crab Cavity Operation in a Hadron Ring	Delayen, Jean
235261	BNL		Collaboration	Wu, Qiong
235311	TJNAF		Collaboration	Krafft, Geoffrey
235335	BNL	Lead	Strong hadron cooling with micro-bunched electron bea	Willeke, Ferdi
235339	ANL		Collaboration	Zholents, Alexander
235343	SLAC		Collaboration	Stupakov, Gennady
235352	TJNAF		Collaboration	Zhang, Yuhong

Most awards going to collaborative proposals

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List of FY2018 FOA Awards Page 2

Proposal ID	Institution	Collab. num.	Proposal Title	PI
235372	Cornell		High current electron sources for strong hadron cooling and polarized sources for EIC	Bazarov, Ivan
235236	BNL	Lead	High Gradient Actively Shielded Quadrupole	Wanderer, Peter
235273	LBNL		Collaboration	Sabbi, GianLuca
235324	TJNAF		Collaboration	Michalski, Timothy
235258	BNL	Lead	Development of an absolute polarimeter and spin-rotat	Raparia, Deepak
235336	MIT		Collaboration	Milner, Richard
235251	ANL	Lead	High Bandwidth Beam Feedback Systems for a High L	Conway, Zachary
235345	TJNAF		Collaboration	Rimmer, Bob
235303	TJNAF	Lead	Development of innovative high-energy magnetized electron cooling for an EIC	Benson, Stephen
235373	ODU		Collaboration	Krafft, Geoff
235277	FNAL		Collaboration	Piot, Philippe
235259	BNL		Collaboration	Blaskiewicz, Michae
235371	NIU		Studies of Conventional and ERL-Based Re-circulator Electron Cooling for an Electron Ion Collider	Erdelyi, Bela
		Total	**8802**	

- **Funding level**: FY 18 Enacted: $8.8M

Summary Remarks

- With the 2015 NSAC LRP recommendation for an EIC, NP has developed a near-term plan for moving forward with an EIC:
  - A NAS study of merits of US-based EIC
  - An NP community panel review for setting priorities for EIC accelerator R&D
  - Increased accelerator R&D funding

- The realization of an EIC will require development of many cutting-edge accelerator technologies, securing U.S. leadership in accelerator R&D in the long-term.

- NP has a great deal of accelerator science expertise within its portfolio, with three operating accelerator Scientific User Facilities, and a fourth under construction (FRIB).

- NP will continue to support and nurture the core competencies needed to implement an EIC and will continue EIC R&D.

END