Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY

Collider-Accelerator Department Machine Advisory Committee

Wolfram Fischer
Deputy Associate Laboratory Director for Accelerators, NPP
Chair, C-AD

C-AD Machine Advisory Committee

17 December 2025

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Committee Members

- Sasha Valishev, FNAL – Chair
- Richard Scrivens, CERN
- Andreas Lehrach, RWTH Aachen
- Uli Wienands, ANL
- Yoichi Sato, J-PARC/KEK
- Ralph Assmann, GSI

Collider-Accelerator Department facilities

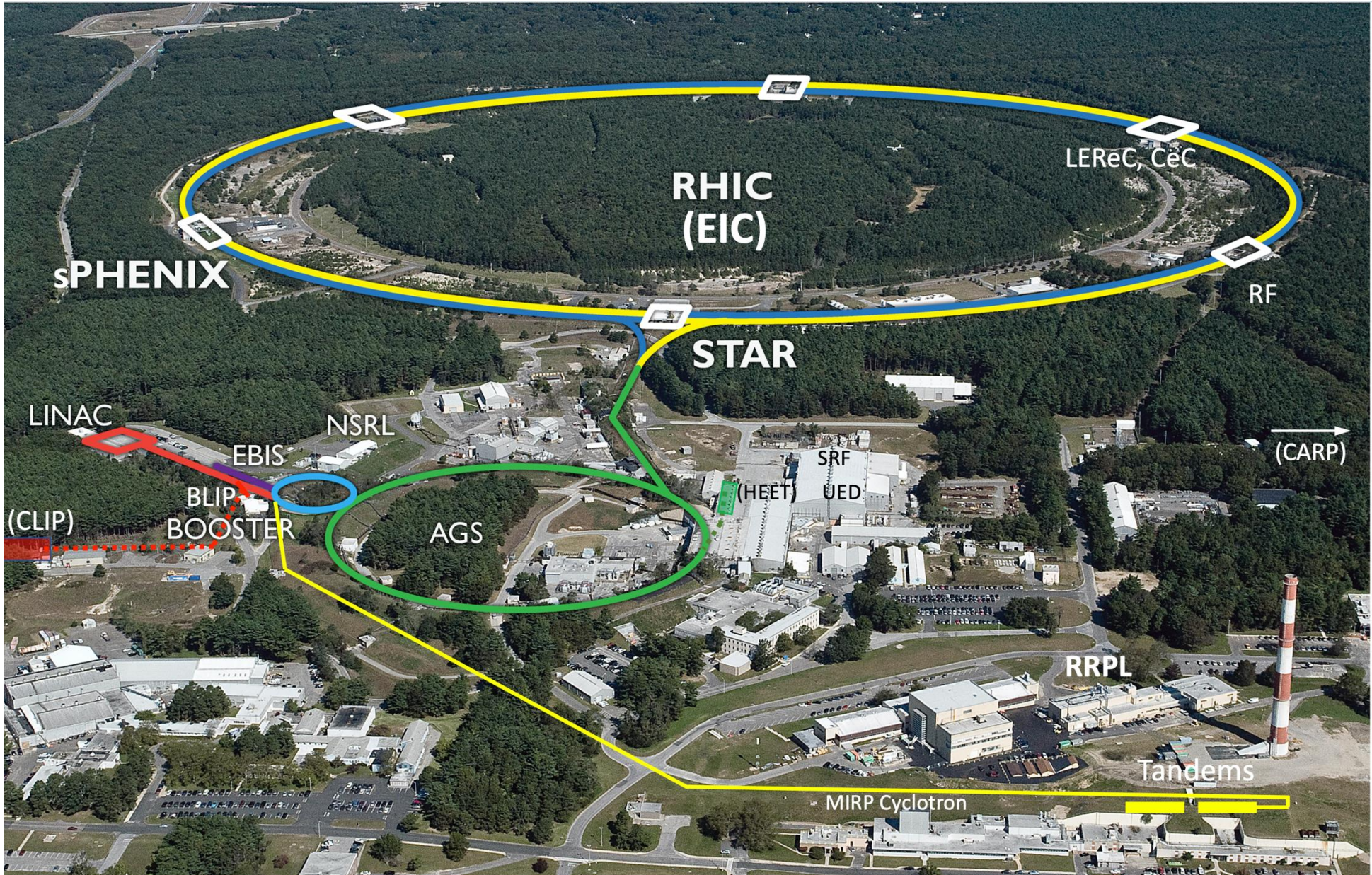
Uniquely flexible and only hadron collider in US for exploration of QCD phase diagram and proton spin

Injectors also used for application programs:

- Linac/BLIP for isotope production
- Booster/NSRL for space radiation studies
- Tandem for industrial/academic users

R&D for future facilities and application

sources, cooling, pol. beams, …



C-AD in transition – RHIC to EIC

- RHIC beam operations to end no later than 28 Jan 2025
  - Last Au+Au collision at 100 GeV/nucleon on 8 Dec 2025, 08:45:20
  - Presently colliding polarized p+p (sPHENIX only)
  - Possibly other modes (days)
    - Au FXT at injection energy – STAR only
    - APEX and CeC
- Followed by several tests (PS, RF, LEReC)
- Then transition to a new mode

Final Run-25 Au+Au

- damaged 69 kV power line
- repair shut off Central Cryo Plant
- required managing helium inventory
- 15 days

- short in superconducting bus
- repair required partial warm-up
- opened several cryostats
- 65 days

- unsynchronized beam abort
- Yellow abort vacuum repair
- 14 days

Run Coordinator:
Travis Shrey

C-AD in transition – RHIC to EIC

DOE Review for Injector Operations and RHIC Removals and Repurposing (R&R)

8-10 Sep 2025, remote reviewers

DOE NP funded activities from end of RHIC program to start of EIC operations

8 Recommendations (3 submitted, 2 by 31 Dec, 3 by 31 Jan 2026)

BNL NP operations scope – after RHIC conclusion

- Part of the EIC Portfolio – but not EIC Project
- BNL NP Operations
  - Recurring effort from end of RHIC operation to beginning of EIC operation
  - Hadron Injectors and Technical Infrastructure <= MAC-22
  - Experimental Support
  - Regular upgrades <= MAC-22
  - ESH, ARRs
  - Research and Development <= MAC-22

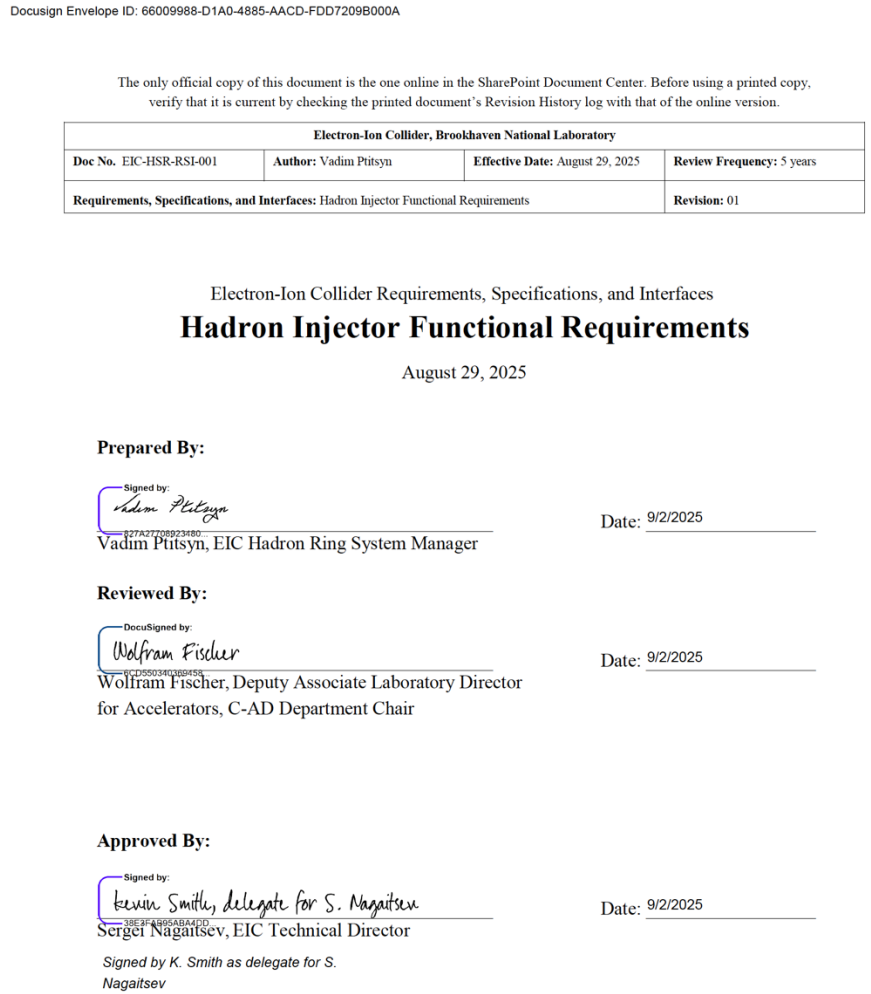
- RHIC Removal and Repurposing Project (R&R)
  - Project with scope, cost, schedule (not under O 413.3B)
- Large Upgrades Projects needed for EIC
  - Project with scope, cost, schedule (not under O 413.3B) <= MAC-22

BNL NP Operations

EIC Requirements for Hadron Injectors

- Beam parameters (in table)
- Support 85% EIC availability
  (RHIC 85.0% 10-year average 2015-2024)
- Beam ready when needed for EIC
- Captured in formal document →

Parameter	p	d	h	Au
Charge number Z	1	1	2	79
Mass number A	1	2	3	197
Injection Energy [GeV]	23.8	12.2	11.1	9.8
Bunch Intensity [10^{10}]	32	15	13	0.23
RMS norm. emittance, h/v [mm]	2.5	2	2	2
RMS long. emittance [10^{-3} eV·s]	42	42	35	42
Polarization [%]	72	-	72	-



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Electron-Ion Collider, Brookhaven National Laboratory			
Doc No. EIC-HSR-RSI-001	**Author:** Vadim Ptitsyn	**Effective Date:** August 29, 2025	**Review Frequency:** 5 years
Requirements, Specifications, and Interfaces: Hadron Injector Functional Requirements			**Revision:** 01

Electron-Ion Collider Requirements, Specifications, and Interfaces

Hadron Injector Functional Requirements

August 29, 2025

Prepared By:

Signed by: Vadim Ptitsyn 827A2770892348D...

Vadim Ptitsyn, EIC Hadron Ring System Manager — Date: 9/2/2025

Reviewed By:

DocuSigned by: Wolfram Fischer 6CD55034038B458...

Wolfram Fischer, Deputy Associate Laboratory Director for Accelerators, C-AD Department Chair — Date: 9/2/2025

Approved By:

Signed by: Kevin Smith, delegate for S. Nagaitsev 38E3F6B95ABA4DD...

Sergei Nagaitsev, EIC Technical Director — Date: 9/2/2025

Signed by K. Smith as delegate for S. Nagaitsev

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Hadron Injectors

- High-intensity high-brightness pulsed ion sources
  (Laser Ion Source, polarized proton and He-3 source, high-intensity H^- source)
- Electron Beam Ion Source (EBIS)
- H^- Linac (200 MeV, 120 m long)
- AGS Booster (1.5 GeV p / 100 MeV/n ions, C = 200 m)
- Alternating Gradient Synchrotron (AGS)
  (25 GeV p / 10 GeV/n ions, C = 800 m)
- Transfer lines between these machines and to HSR (YD26)
- Mid-term R&D for
  sources, polarized beams, beam cooling

[Tandems not included – self supporting]

Technical Infrastructure

- Shop areas (power supplies, vacuum, instrumentation, RF, cryo, electronics and experimental support)
- Test areas (primarily experimental hall bldg. 912)
- Equipment buildings for hadron injectors, experiments and RHIC/HSR (not office buildings) – approximately 100 buildings

Cost Summary – BNL NP Operations

- For annual effort to maintain Hadron Injectors and Technical Infrastructure, perform regular Upgrades, and Experimental Support
- After RHIC operation concludes, in FY26$

			Labor K$		M&S K$		TOTAL K$	
OBS		FTE Total	Direct Labor $ Total	Burdened Labor $ Total	Direct M&S	Burdened M&S	Direct TOTAL	Burdened TOTAL
1	Operations (Direct FTEs only)	166.4	33,963	69,113	28,974	37,252	62,936	106,366
1.1	Management and Org Functions	28.1	0	0	0	0	0	0
1.2	Program Support	0.0	0	0	9,813	12,608	9,813	12,608
1.3	Accelerator Operations and Research *	40.5	9,030	18,978	3,491	4,387	12,521	23,365
1.4	Accelerator Systems	60.8	11,258	23,659	4,448	5,252	15,706	28,911
1.5	Infrastructure and Technical Support	30.7	5,560	11,685	6,974	9,605	12,535	21,290
1.6	Experimental Support	34.5	8,114	14,792	4,248	5,400	12,362	20,192

RHIC Removals and Repurposing (R&R)

Large Upgrade Projects Required for EIC

[time-limited efforts, not DOE 413.3B]

RHIC Removals and Repurposing (R&R)

- RHIC R&R is a project with scope, cost, schedule
  (not under DOE project order O 413.3B)

- Preparation of the present RHIC tunnel for EIC construction:
  - EIC uses only one of the RHIC hadron rings as the Hadron Storage Ring (HSR)
  - EIC adds Electron Storage Ring (ESR) in tunnel
- Removal of RHIC equipment not used by EIC from tunnel and experimental halls
- Delivery of some equipment to EIC for Repurposing
- R&R has low technical risk, dominated by labor

RHIC Removals and Repurposing (R&R)

- Based on Project Definition, BOE, and DOE G 413.3-21A (Jun-2018) Cost Estimating Guide, appropriate range estimate is Class 2 (L: -5% H: +20%)
- Project Contingency assigned is 20% applied to the BAC
- Predominantly Labor project, 85% Labor and 15% Nonlabor
- Nonlabor is comprised of Muon Wall contractor and general material consumables across all WBS elements within Project Oversight

WBS #	WBS Title	Point Estimate K$	Labor	Nonlabor
27.01	Project Oversight	15,123	11,850	3,273
27.02	Accelerator Ring	38,774	36,266	2,508
27.03	sPHENIX	4,428	4,428	0
27.04	STAR	8,340	8,340	0
27.05	Muon Wall	18,975	10,074	8,900
	Total Budget At Completion (BAC)	**85,640**	**70,958**	**14,681**
	Contingency (20%)	17,128	14,192	2,936
	Total Project Cost (TPC)	**102,768**	85,150	17,618

Technical driven schedule:
FY2026 to FY2029 w/o Muon Wall; to FY2031 w/ Muon Wall
Funding profile $30M / $30M / $43M

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Large Upgrade Projects in Order of Priority

Upgrade projects with funding needs beyond the assumption in recurring BNL NP Operations budget ($3M/y for AIP+CE):

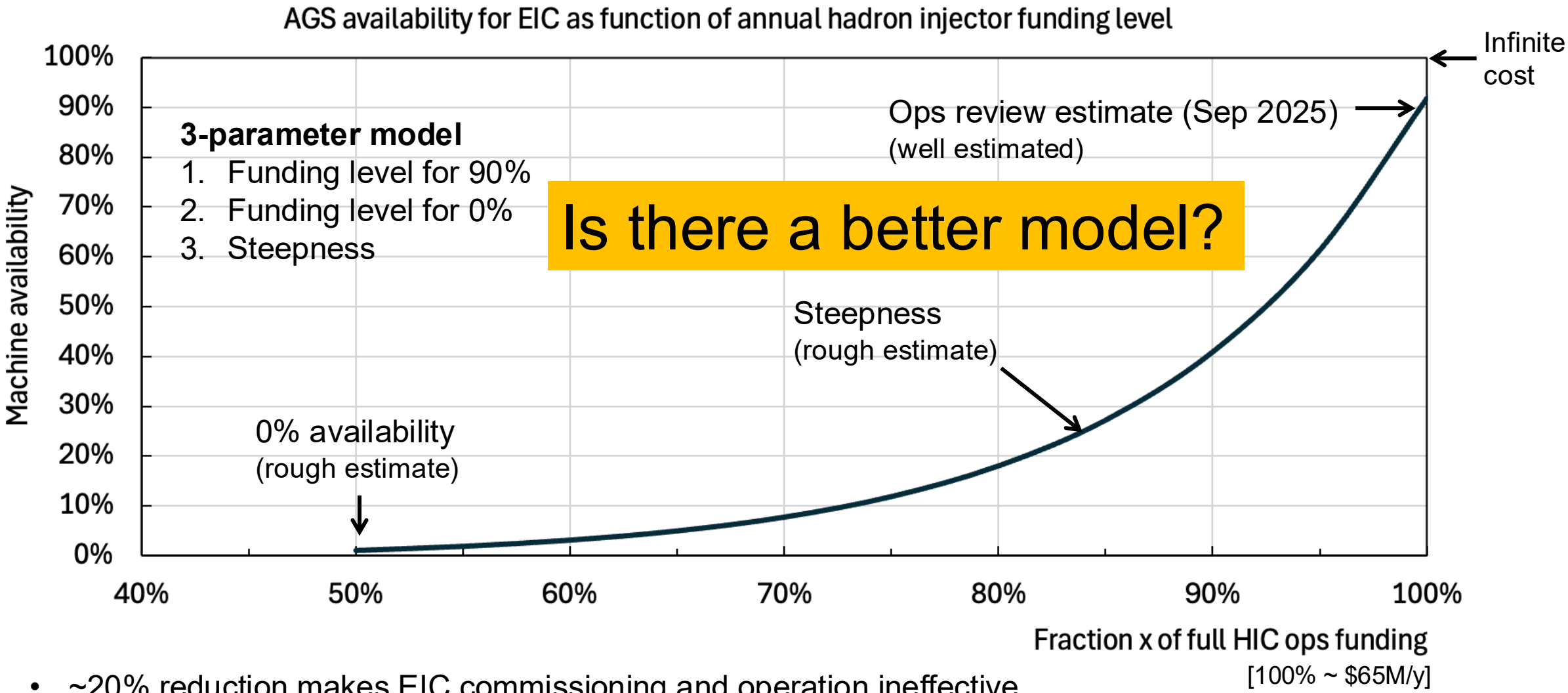
1. Central Cryo Plant Upgrade ($34.0M)
2. SRF Test Facility Upgrade ($17.7M)
3. LINAC RF Power Amplifier Upgrade Phase I ($12.7M)
   (start of conversion from triode to solid state, Phase II ~$88M)
4. AGS Cooling Water System Upgrade ($9.1M)

Additional uses of hadron injectors

- Operation of Linac for DOE isotope production at BLIP
  [BLIP = Brookhaven Linac Isotope Producer, incremental costs recovered]

- Operation of LION/EBIS/Booster for space radiation studies
  [LION = Laser Ion Source, EBIS = Electron Beam Ions Source,
  NSRL = NASA Space Radiation Laboratory, incremental costs recovered]
- NASA Space Radiation Lab (NSRL) at BNL is a unique national test facility for
  - Space biology
  - High-Energy (>100 MeV/nucleon) space electronics testing

Model of EIC hadron injector availability vs HIC funding



- ~20% reduction makes EIC commissioning and operation ineffective
- idles EIC for long periods at ~$300M/y EIC ops budget
- could take a decade to reach 85% DOE availability requirement (cf CEBAF)

Recommendations from MAC-21

MAC-21 recommendation responses

RHIC Performance in Run-24 and planning for Run-25

R1: The nature of the instabilities encountered (*during scrubbing run with p*) should be described in more detail. => Michiko Minty

R2: Define a strategy for the 56 MHz cavity before the start of the run, that achieves an optimal trade-off between invested time and expected performance gain. => Michiko Minty

Experimental background in Run-24 and sPHENIX MVTX experimental background task force

R3: Calculate the overall aperture bottleneck for a betatron halo particle (at a setting of horizontal collimator, e.g. 8 sigma-beta-x) that at the same time has an energy offset at the momentum aperture (e.g. 4.5 sigma-E). Use the known local aperture, the horizontal beta function and the horizontal dispersion to see if such a particle can get lost at the second taper in front of sPHENIX or at another "high impact" location that can shine into the detector. Only if this is true, a global momentum collimation can safely protect the experiment. Otherwise, local origins of off-momentum ions might be responsible, to be counteracted by local protection measures.
=> Michiko Minty

R4: Check the dependence of background on bunch intensity and horizontal collimator settings.
=> Michiko Minty

R5: The addition of local shielding in sPHENIX seems like a good idea and should be done before Run-25 if at all possible.
=> Michiko Minty

MAC-21 recommendation responses

Injector upgrade plans over the next decade

R6: Continue optimizing the modernization plan and produce a prioritized list of tasks for next year's review. => Rob Michnoff

CeC status and plans for Run-25

R7: Overcome the lack of reliability: both in terms of beam parameter jitter and poor repeatability of operation set-ups. => Alexei Fedotov

R8: Develop a Plan B to continue the CeC development after the RHIC shutdown. => Alexei Fedotov

Polarization increase with AGS skew quads in Run-24

R9: Consider installing a polarized gas target to get an absolute polarization measurement that would help to track the polarization in the accelerator chain. => Frank Rathmann

R10: In Run-25, prioritize addressing model inaccuracies at energies below transition. => Kiel Hock

Physics-informed ML for polarization increase in injectors (FOA)

R11: At the next MAC, present a summary of the usage of the optimization tools created for BNL accelerator operations. => Kevin Brown

MAC-21 recommendation responses

BNCT lithium beam driver (LDRD 24-046)

R12: For MAC-22, clarify the scope of responsibilities among collaborators and highlight the BNL part.

=> Masahiro Okamura

EBIS Status and Performance

R13: At the MAC-22 present the plans and schedule for the polarized 3He development. => John Ritter

FFA synchrotron for medical applications (LDRD 24-010)

R14: 3D field maps including fringe fields should be incorporated in beam simulation, and the necessary dynamic aperture demonstrated. Correction schemes should also be investigated. => Dejan Trbojevic

High Energy Cooling R&D

R15: Consider engaging external partners (e.g. university faculty, graduate students) to accelerate the work on HEC options. => Alexei Fedotov

R16: Begin work towards an integrated assessment of beam dynamics in EIC hadron cooling (i.e. start-to-end simulation) for the HEC options. => Alexei Fedotov

MAC-22 Charge

MAC-22 Charge

After 25 years of RHIC operation, the Collider-Accelerator Department (C-AD) is concluding the final RHIC Run with the new sPHENIX and the upgraded STAR detectors in January 2026. After completion of the RHIC physics programs, C-AD will assume responsibility for removal of equipment not needed for the EIC from the RHIC tunnel and experimental halls, will maintain the hadron accelerator complex in a ready state, operate the hadron injectors for isotope production at BLIP and space radiation studies at NSRL, and will continue R&D in accelerator science and technology.

During this year's MAC we request the committee's review and advice on (i) the plans for maintaining and upgrading the hadron injector complex over the next 3 years and beyond, and (ii) the strategy and efforts of the C-AD R&D efforts.

Please address the following charge questions:

a) Comment on possible models of availability as a function of funding, and risks associated with single points of failure.

b) Are the C-AD plans aligned with the EIC goals over the next decade?

c) Are the present efforts well executed, and future work well planned?

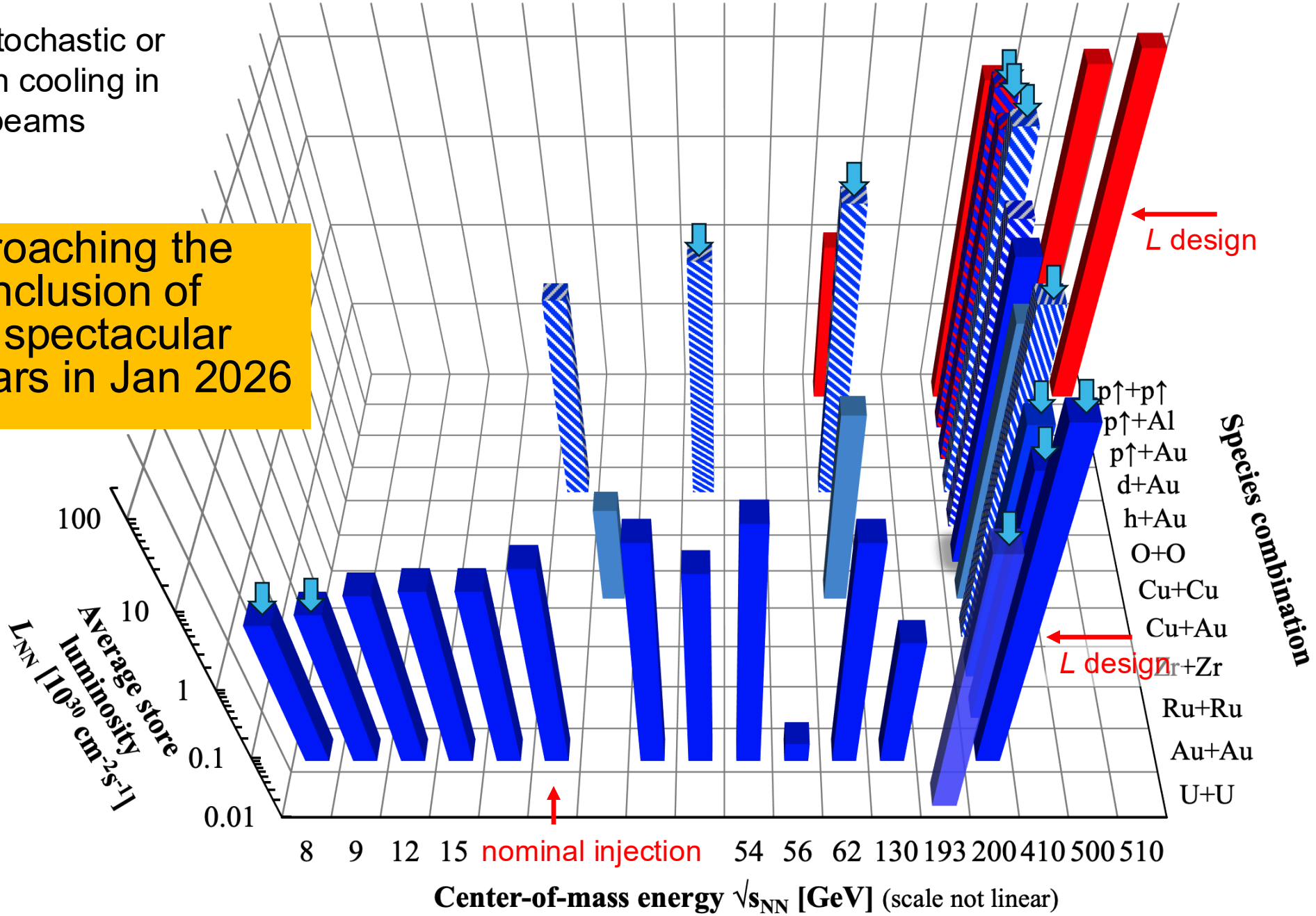
Any other comments on the C-AD accelerator operation and R&D are welcome.

It is requested that a concise report responsive to this charge be forwarded to the C-AD Chair, Wolfram Fischer, by 5 January 2026.

RHIC energies, species combinations and luminosities

Used stochastic or electron cooling in 1 or 2 beams

Approaching the conclusion of 25 spectacular years in Jan 2026



Thank you

MAC advice was essential
for advancing the RHIC program