Non-HEP Accelerator R&D, Synergies and Timescales, Workforce

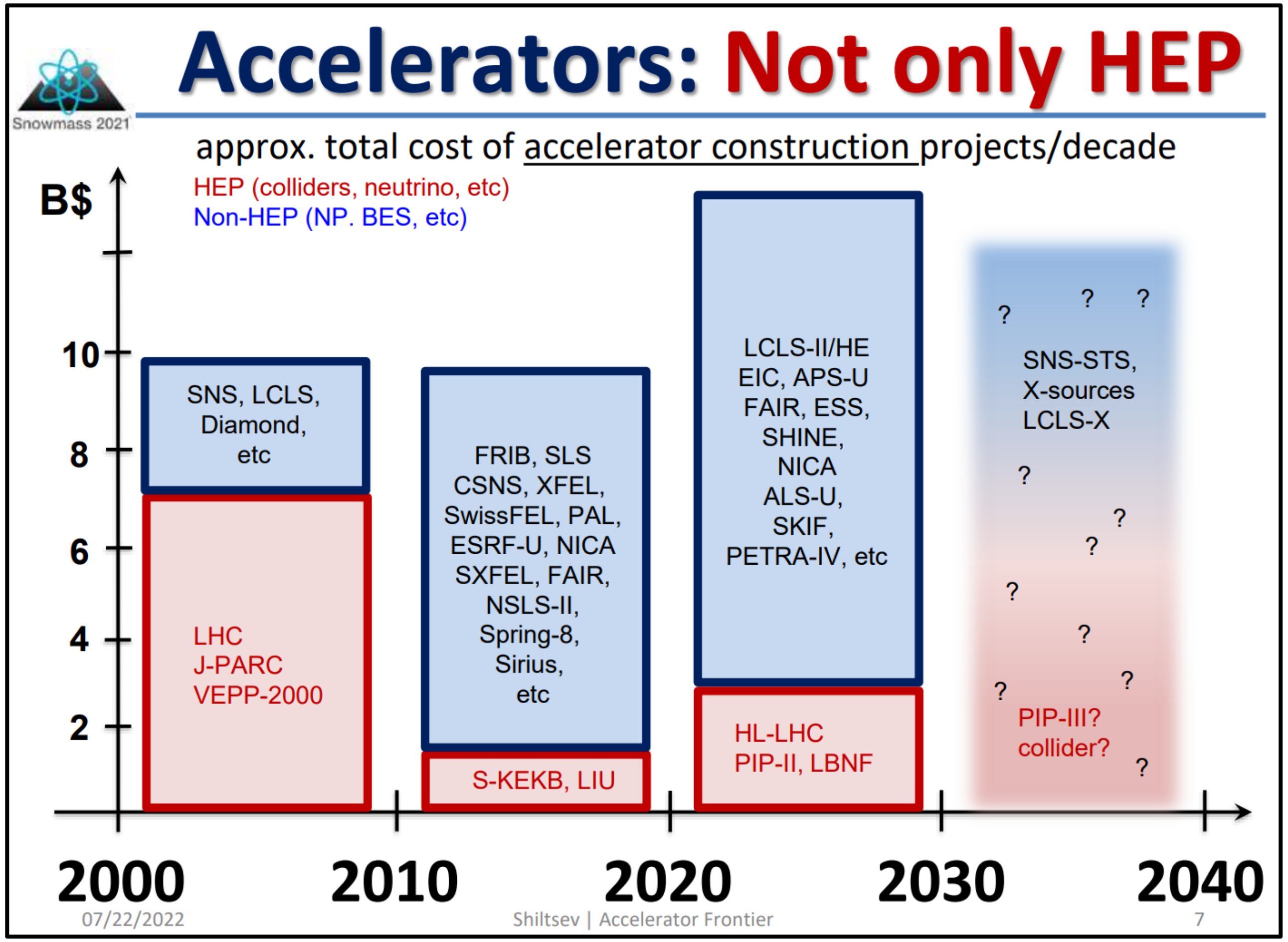
Michiko Minty

P5 Town Hall, hosted by SLAC National Accelerator Laboratory

3 May 2023

@BrookhavenLab

Reminder from Snowmass (July 2022)



Note: NSAC LRP (for FY2023 – FY2032) expected this CY
Update to BES 20-year facilities roadmap TBD

Accelerator Frontier Vision

Conveners: S. Gourlay, T. Raubenheimer, V. Shiltsev

https://indico.fnal.gov/event/22303/contributions/245315/attachments/157756/207133/AF_Colloquium_CSS_072222_v5.pdf

"Accelerator development should be part of P5: planning for accelerators should be aligned with the strategic planning for particle physics and should be part of the P5 prioritization process".

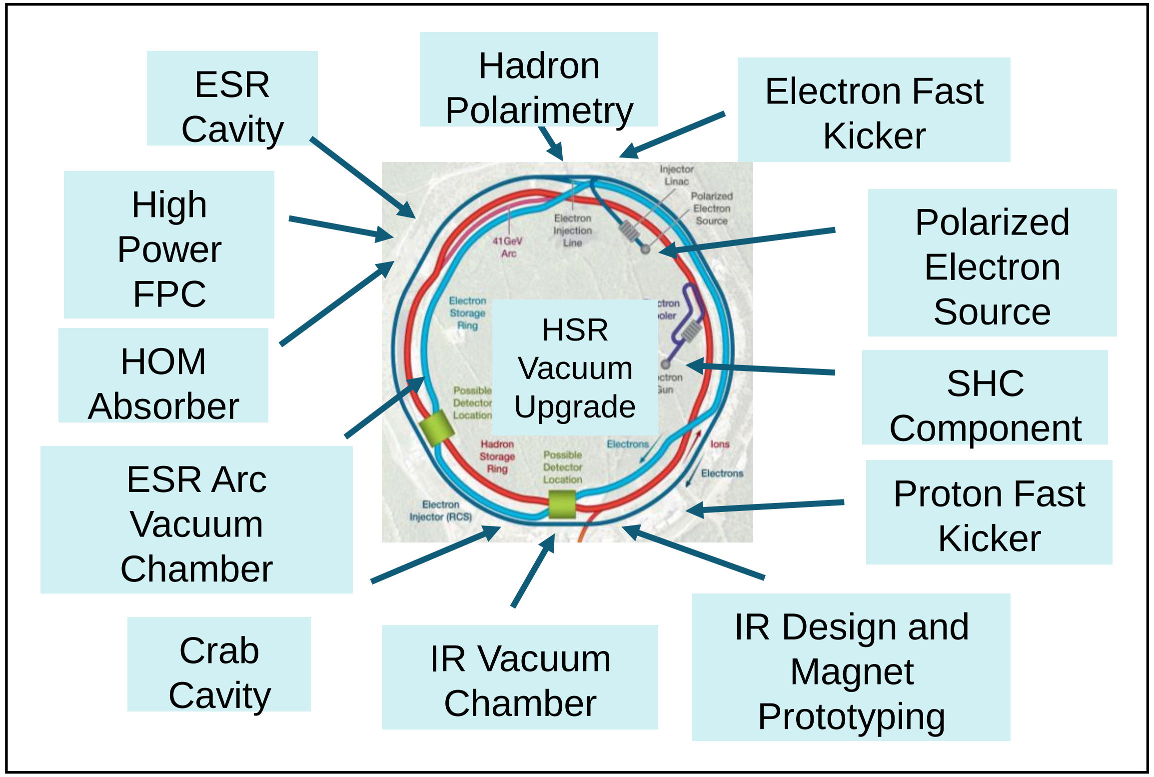
Electron Ion Collider (EIC)

The **LAST operating collider in the America's**, the Relativistic Heavy Ion Collider, will operate for only three more years. It be succeeded by the (NP-funded) Electron-Ion Collider. Challenging design parameters require much accelerator R&D synergistic with potential P5 priorities.

Synergies between EIC and future collider designs already being studied: the US Accelerator Physics community is coordinating with the highest-priority initiative of the 2020 European Strategy for Particle Physics - an electron-positron based Higgs factory. The EIC and FCC-ee have common accelerator-based challenges being collaboratively addressed:

- FCC-EIC Joint & MDI Workshop (Oct 2022) https://indico.cern.ch/event/1186798/
- EIC Workshop – Promoting Collaboration on the EIC (Oct 2020) https://indico.cern.ch/event/949203/
- First annual US FCC workshop (May 2023) https://www.bnl.gov/usfccworkshop/

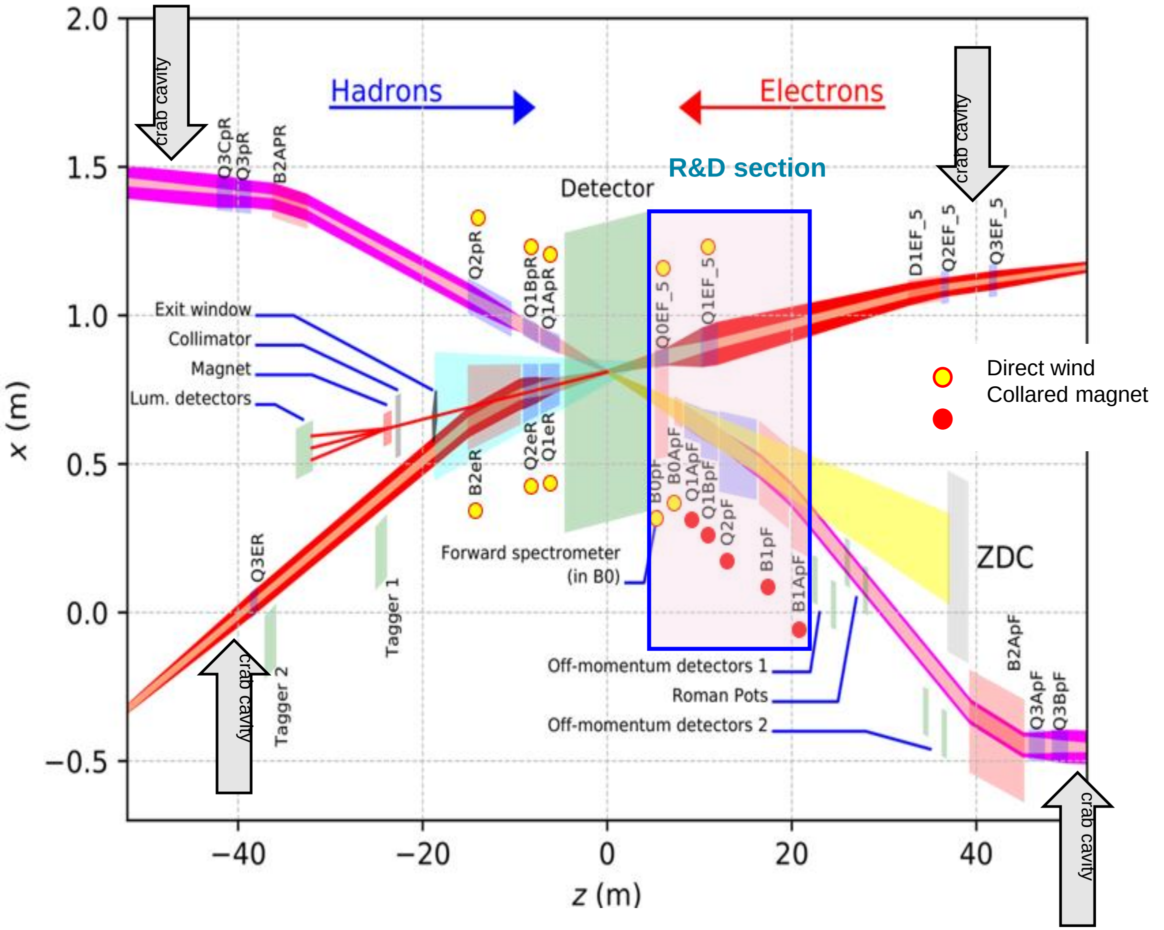
Overview of EIC R&D and pre-production prototypes



Select examples on next slides.

Electron Ion Collider: Interaction Region Design

Layout of the EIC Interaction Region



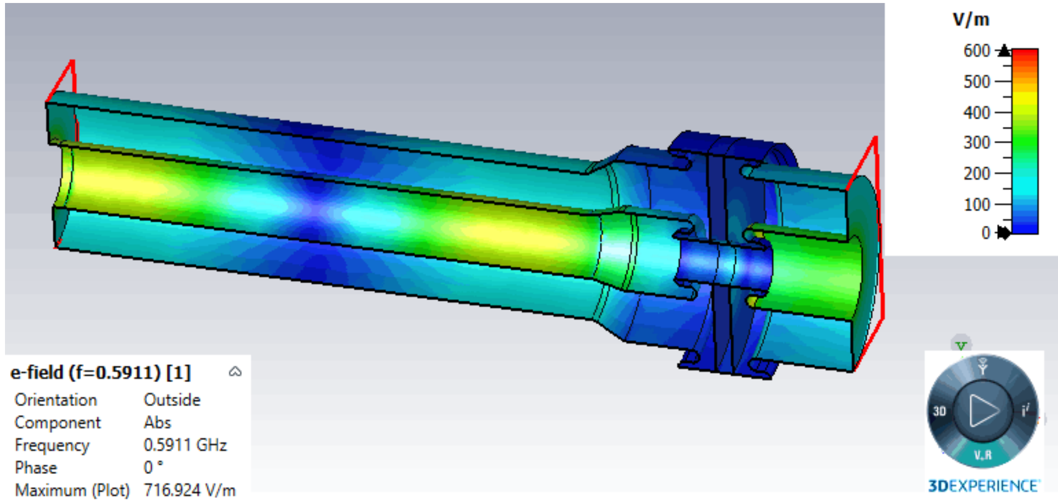
Synergies

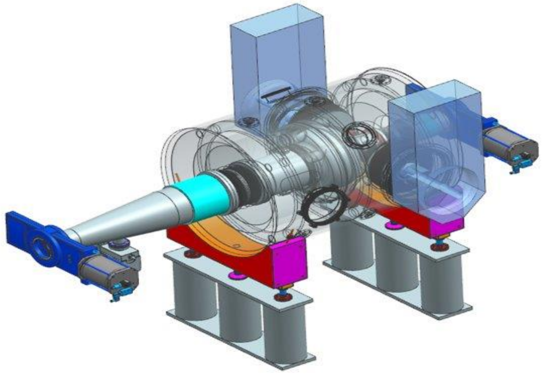
- modeling and simulations for dynamic aperture, chromatic aberrations, beam-beam effects, beamstrahlung, optics correction
- magnet designs and fabrication methods – coil configuration, field quality, coil forces, structural analyses
- quench protection, adjustable collimators
- luminosity monitors, control and measurements of beam losses and backgrounds, machine fault handling

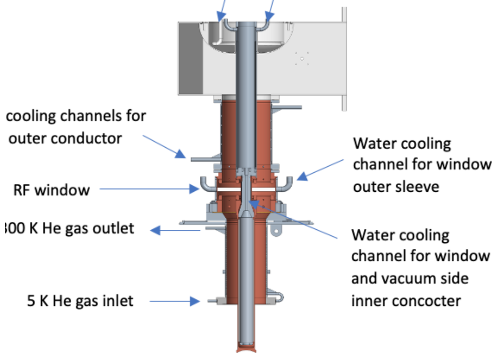
Electron Ion Collider: RF Technologies – high power SRF

Highest CW Power Fundamental Power Coupler

Transmit 500 kW RF power at ~600 MHz

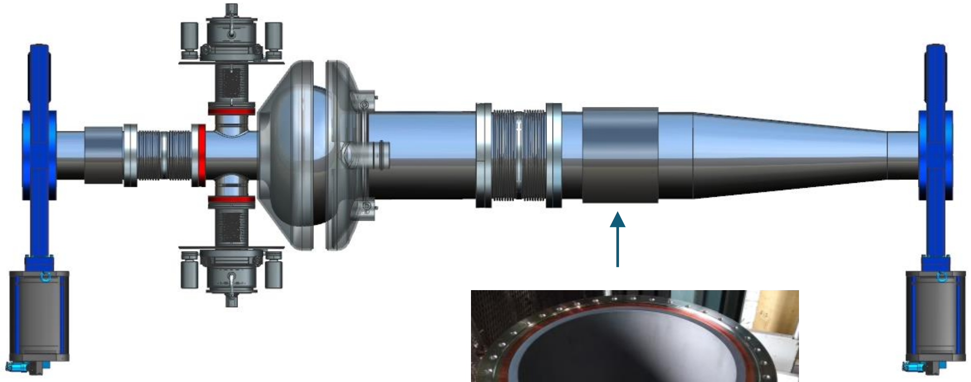


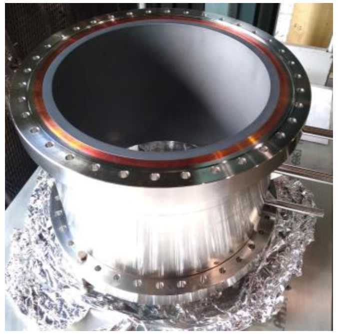




Higher-Order-Mode Absorber

Absorb > 40 kW with large diameter and high thermal conductance





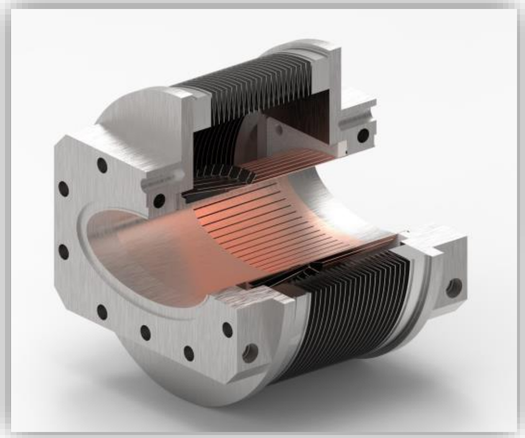
Synergies

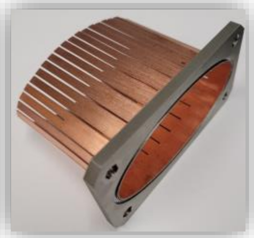
- electromagnetic analyses (wakefields)
- thermal analyses
- detailed mechanical engineering designs
- material evaluations and pressure fitting methods
- RF Test Facilities: high-power test stand

Electron Ion Collider: Vacuum Systems

Synergies: electron accelerator

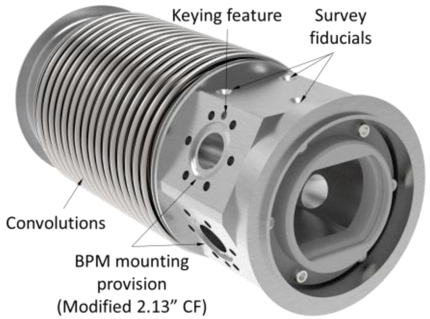
- mechanical designs for shielded bellows
- spring and plating fabrication techniques

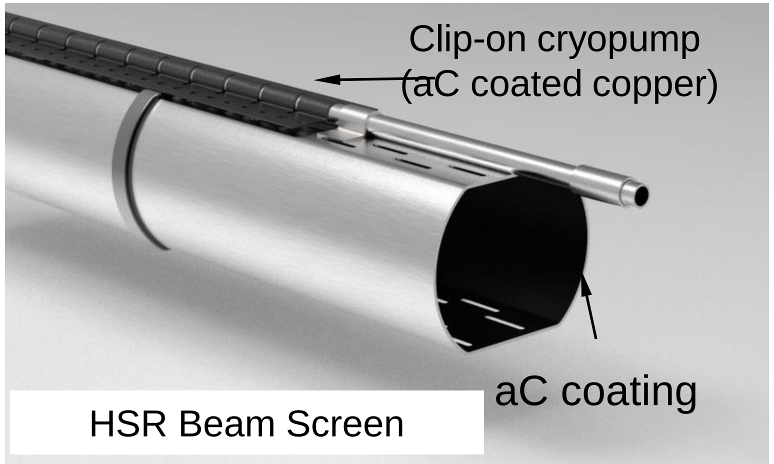




Synergies: hadron accelerator

- development of chamber coatings with small secondary yield coefficient (SEY) to mitigate beam instabilities due to electron clouds
- low impedance beam screen designs and associated cooling techniques
- Vacuum Test Facility to evaluate residual resistance ratio (RRR), SEY, and adsorption capacity under cryogenic temperatures

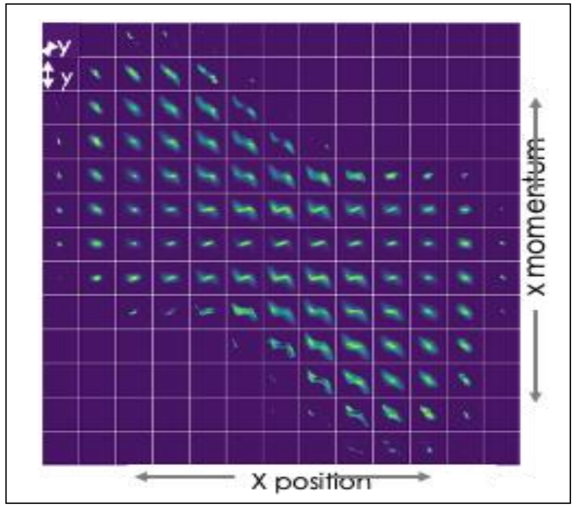




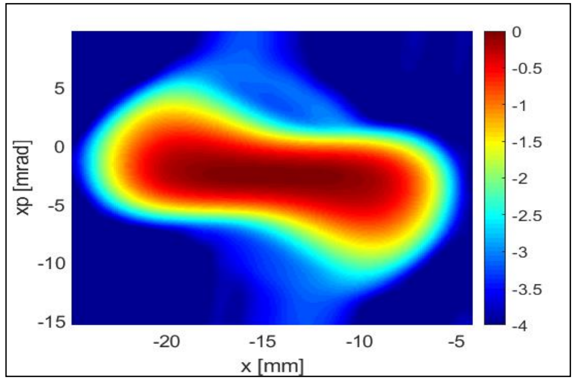
Intensity Frontier – High Intensity Accelerators

Synergies

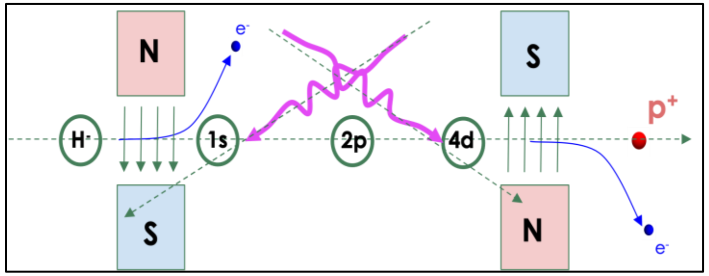
- beam physics: space charge effects and mitigation methods for high efficiency transmission
- R&D in laser assisted charge exchange for H^- injection (SNS)
- Beam Test Facility – full intensity SNS front end
  - ion source technology
  - instrumentation for 6-dimensional characterization of beam distribution (measurements provide initial conditions for subsequent simulations to investigate beam loss and halo formation)
  - high dynamic range (10^{-6}) instrumentation for characterization of beam halo
- Non-invasive instrumentation (advanced laser-based diagnostics) for beam property characterization



Direct 4D phase space measurement at the SNS Beam Test Facility.



High dynamic range measurement of beam halo resolving over 4 orders of magnitude.

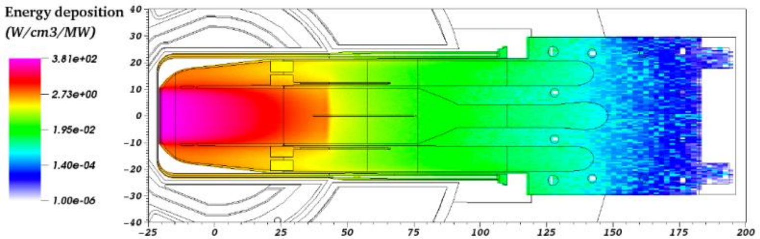


Two-step excitation stripping scheme demonstrated at SNS to reduce laser power requirements.

Intensity Frontier – High Power (multi-MW) Targetry

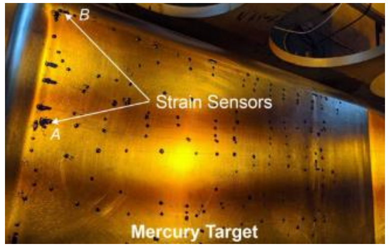
Synergies in innovative accelerator technologies for high power beams

- advanced simulations for optimized geometries

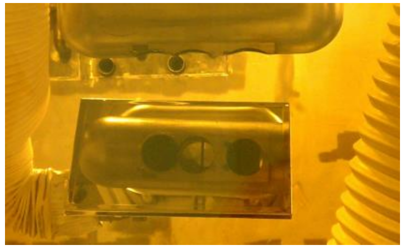


- advanced manufacturing techniques

- instrumentation: radiation-hard sensor development



- material science - Post Irradiation Examination (PIE)



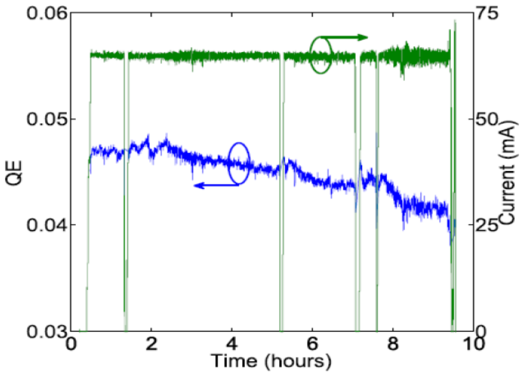
OAK RIDGE National Laboratory
HIGH FLUX ISOTOPE REACTOR | SPALLATION NEUTRON SOURCE

Particle Sources – electron guns

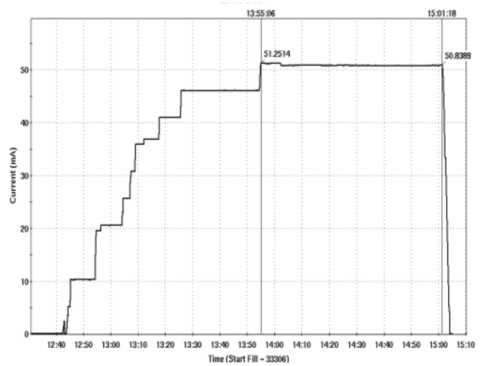
Synergies - all aspects pertaining to high current, high brightness beams with both DC and SRF guns for high-power ERLs and the EIC

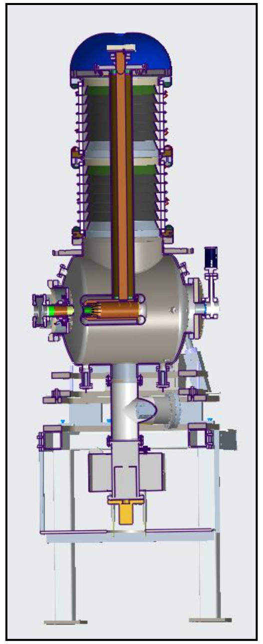
- photocathode research
  - high quantum efficiency
  - photocathode lifetime (e.g. cathode cooling)
- lasers and laser-cathode interactions
- gun cavity designs and extreme high vacuum (XHV) technologies
- modelling and simulations
- polarization

65mA state-of-the-art

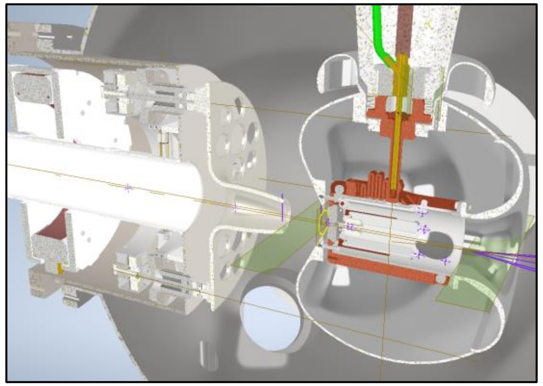


20 mA (routine) ; 50mA demonstrated

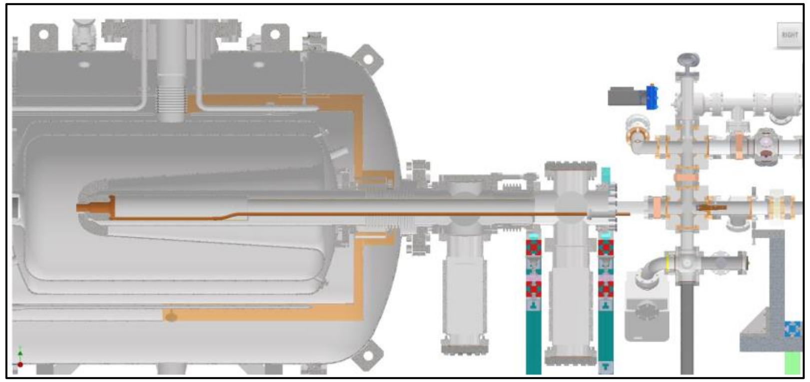




DC gun: 375 kV, 20 mA



EIC gun: 400 kV, 100 mA



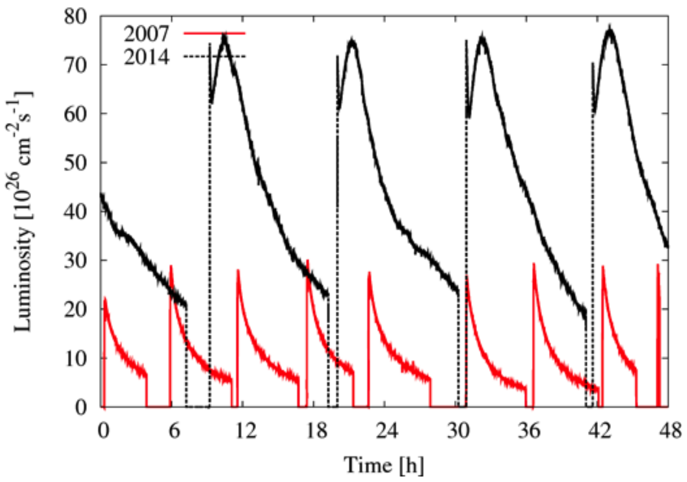
SRF gun R&D: > 1 MV, aim for 1-3 mA, >30 mA with 100 kW FPC

Advanced concepts – beam cooling: progress in last two decades

2005 DC electron cooling applied to relativistic beams (HEP - FNAL)

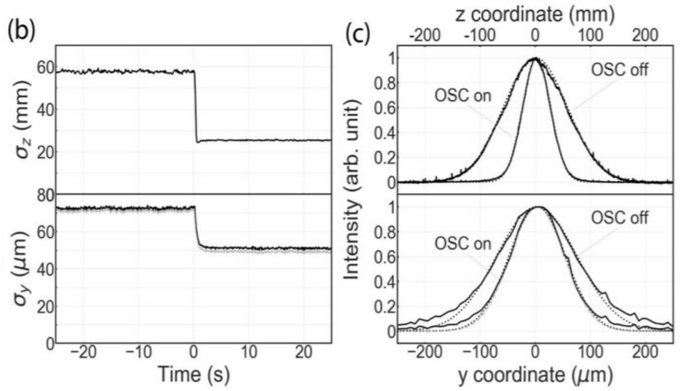
2007 stochastic cooling of ‘bunched’ beams – 10^9 Hz bandwidth (NP)

2010 stochastic cooling in all dimensions (NP - BNL) →



2017 RF bunched-beam electron cooling (NP - BNL)

2022 optical stochastic cooling – 10^{13} Hz bandwidth (HEP – FNAL, IOTA) →



R&D coherent electron cooling – 10^{13} to 10^{15} Hz bandwidth (NP - BNL)

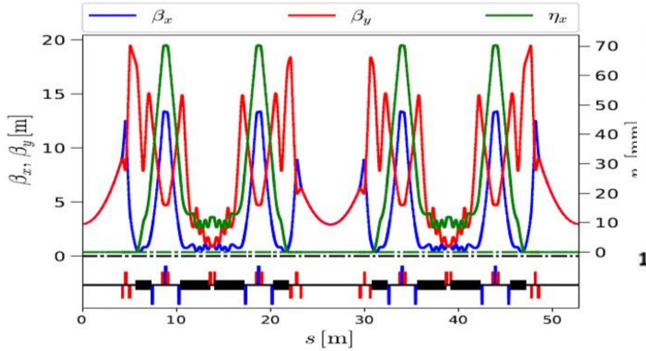
Experimental Demonstration of Relativistic Electron Cooling, PRL **96,** 044801 (2006), S. Nagaitsev et al
Coherent Electron Cooling, PRL **102**, 114801 (2009), V.N. Litvinenko and Y.S. Derbenev
Three-dimensional stochastic cooling in the Relativistic Heavy Ion Collider, PRL **105**, 094810 (2010), M. Blaskiewicz, J.M. Brennan and K. Mernick
Experimental Demonstration of Hadron Beam Cooling Using Radio-Frequency Accelerated Bunches, PRL **124**, 084801 (2020), A.V. Fedotov et al
Experimental Demonstration of Optical Stochastic Cooling: Nature **608**, 287-292 (2022), J. Jarvis et al

Electron Accelerators and Photon Sources (BES/NP)

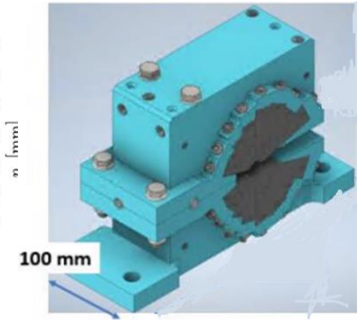
Synergies

- modelling and simulations of ultra-low emittance beams
- vacuum system design with small apertures and high heat loads
- superconducting undulators
- new applications with permanent magnets
  - combined function magnets
  - open mid-plane
- FEL-specific
  - high repetition rate and CW operation
  - exquisite high-precision synchronization
  - advances in speed and accuracy of computations

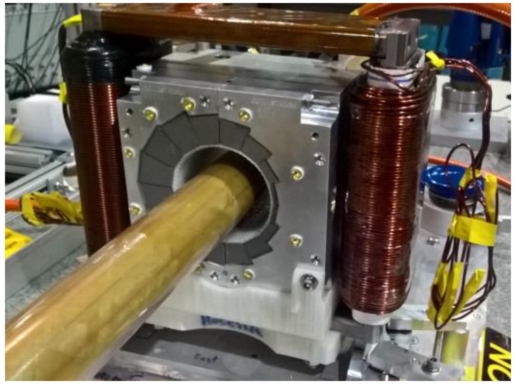
Triple Complex Bend Achromat TCBA design (NSLS-II)



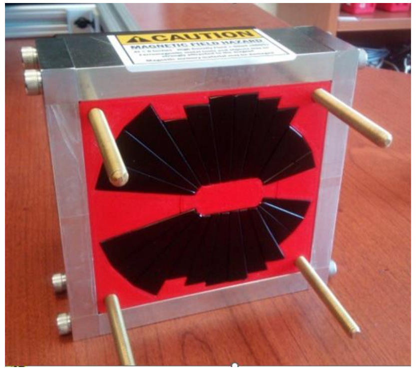
NSLS-II upgrade (complex bend)



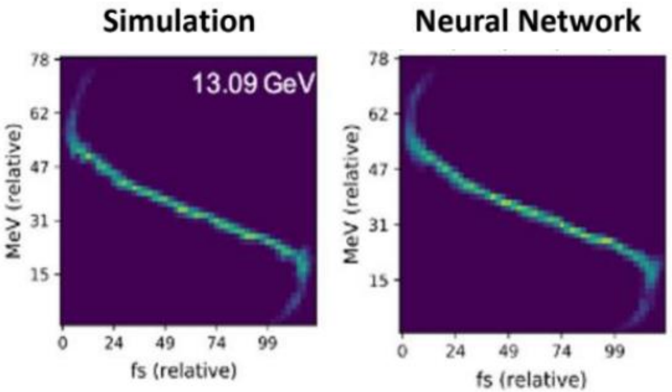
CBETA (SC energy recovery LINAC)



CEBAF 20 GeV upgrade



Neural network surrogate: < ms (10^6 speedup)



Modified Halbach Magnets for Emerging Accelerator Applications, IPAC 2021, S.J. Brooks
Permanent Magnets for the CEBAF 24 GeV Upgrade, IPAC 2022, S.J. Brooks

A note on ARDAP, established April 2020

mission: to coordinate and make accelerator R&D investments aimed at addressing Acc. Sci. & Tech. gaps to ensure that future U.S. accelerator- based physical science R&D priorities will be met; consists of two programs:

Accelerator Research and Development supports

- early-stage (low-TRL) R&D benefitting industrial, medical, and security applications,
- workforce development and capability building at universities
- other R&D activities that **broadly** support the accelerator user community

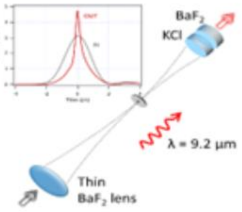
Accelerator Production

- enhance domestic industrial accelerator capability to address potential supply chain vulnerabilities
- consists of two sub-programs: Accelerator Technology Maturation and Accelerator Technology Production

Select FY 2022 R&D awards

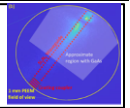
High efficiency, high power lasers

- Colorado State Univ., Univ. Maryland, ORNL, XUV Lasers Inc., Max Born Inst., Few-Cycle Inc.
- BNL, Univ. Central Florida, BAE Systems



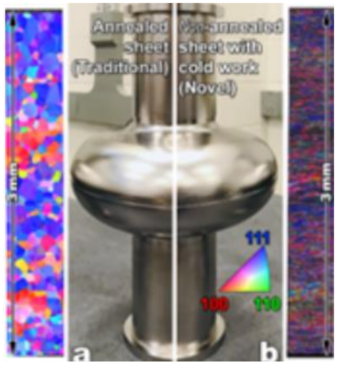
Photocathode development

Arizona State Univ., Univ. of Southern California



Nb SC RF Cavity processing

Florida State Univ., Michigan State Univ., Univ. of Texas at Austin, TJNAF



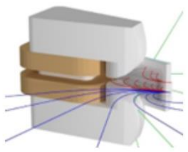
Long-term accelerator R&D:

Simulation of High Energy Density Beams

Univ. of California Santa Cruz, ANL, Radiasoft

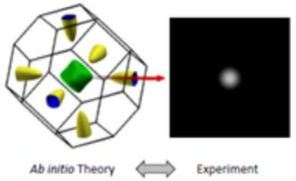
Theoretical and Experimental Studies in Acc. Phys.

Univ. of California Los Angeles



From Theory to Practical High Brightness Photocathodes

Univ. of Illinois at Chicago, SLAC



https://science.osti.gov/ardap/ARDAP-Programs

https://indico.cern.ch/event/995633/contributions/4271350/attachments/2209005/3738151/Colby_OfficeAcceleratorR%26D-Production.pdf

https://science.osti.gov/ardap/Funding-Opportunities/Awarded-RD-Activities

Workforce

United States Particle Accelerator School, USPAS (supported by DOE HEP under GARD, ~$1M/year)

Select institutes

- Center for Advanced Studies of Accelerators (CASA) https://www.jlab.org/accelerator/casa
- Cornell Laboratory for Accelerator-based ScienceS and Education (CLASSE) and the Center for Bright Beams (supported by NSF) https://www.classe.cornell.edu/About/WebHome.html
- Center for Accelerator Science and Education (CASE) at Stony Brook University (supported by DOE HEP) https://news.stonybrook.edu/university/developing-the-next-generation-of-particle-accelerator-talent/

New initiatives recognizing diminishing expertise in accelerator R&D, projects, and operation in the US and increased demand:

- DOE OS: $17.5M for Particle Accelerators for Science and Society and Workforce Training (Aug, 2021)
  - $6.5M – in the Accelerator Stewardship Program with focus on R&D to make accelerator technology widely available
  - $3.0M – Traineeships at Old Dominion Univ. (continued)
  - $8.0M – Three graduate-level traineeship programs (10 universities existing instrumentation programs in HEP detector technologies)

  https://www.energy.gov/science/articles/department-energy-announces-175-million-particle-accelerators-science-society-and

MSU cryo-initiative – collaboration between FRIB and MSU College of Engineering (DOE-SC NP)
https://frib.msu.edu/science/ase/cryogenic/index.html#:~:text=The%20MSU%20Cryogenic%20Initiative%3A,of%20cryogenic%20technology%20and%20skills.

Supported by the DOE OS: Reaching a New Energy Sciences Workforce (RENEW) and Funding for Accelerated, Inclusive Research (FAIR) to support undergraduate and graduate levels geared towards increasing participation and retention of under-represented groups, impact on accelerator R&D TBD.

HEP provides majority of funding for workforce training in accelerator R&D. This complements the significant workforce not funded by HEP driven by support of projects and their upgrades.

Summary and perspectives

Accelerator R&D supported by non-HEP funded laboratories and universities, as well as ARDAP and I.FAST (in Europe), are in many cases synergistic with the needs of the HEP community.

Non-HEP funded accelerator R&D is largely project-driven with commensurate time scales. Some overlap exists with GARD thrusts (e.g. in beam physics, particle sources, and targetry).

Training of next generator accelerator scientists, engineers, and technicians for future P5 directives likely to strongly benefit from the non-HEP community. Yet availability of technical expertise seems incommensurate with the design, construction, and operation of a future high energy, US-based collider.

- Construction and operation of the Electron Ion Collider (EIC) shall preserve expertise could however require much of the nation's accelerator-based R&D and production resources.
- Successful design, construction, and operation of the EIC seems a prerequisite to any future US-based collider.

The P5 planning process for future colliders should consider how best to leverage overlaps with non-HEP accelerator R&D as part of the national HEP plan.

From the Accelerator Frontier: "Accelerator development should be part of P5: planning for accelerators should be aligned with the strategic planning for particle physics and should be part of the P5 prioritization process".

Acknowledgements

For this presentation, received input and advice from a number of colleagues representing a sampling of the collective work in non-HEP accelerator R&D and workforce development for which I am very grateful:

Vladimir Shiltsev, Sergei Nagaitsev, Dmitry Denisov, Wolfram Fischer, Qiong Wu, Wencan Xu, Sarah Cousineau, Timur Shaftan, John Hill, Subashi De Silva, John Byrd, Andri Seryi, DejanTrbojevic, Derun Li, Joe Grames, Zhirong Huang, Alexei Fedotov, Maria Chamizo Llatas, Cliff Brutus, Deepak Raparia, Alex Zaltsman, Steve Lund, Stephen Brooks