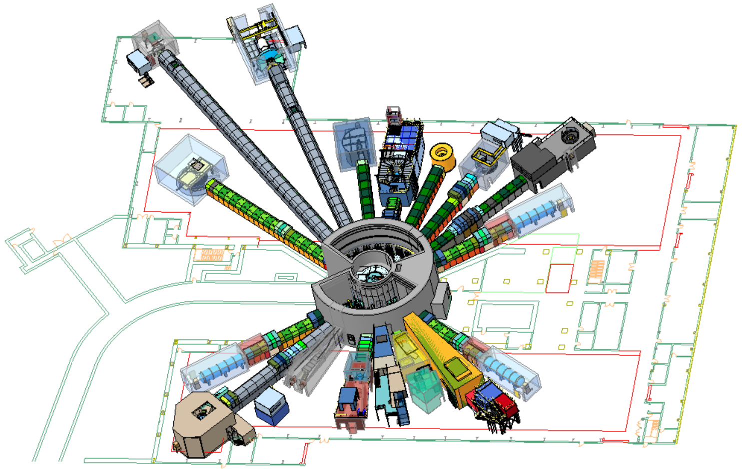
Basic Research Needs Workshop on Accelerator-Based Instrumentation

Co-chairs: Laurent Chapon (ANL), Richard Ibberson (ORNL)
BES POC: Eliane Lessner (BES)

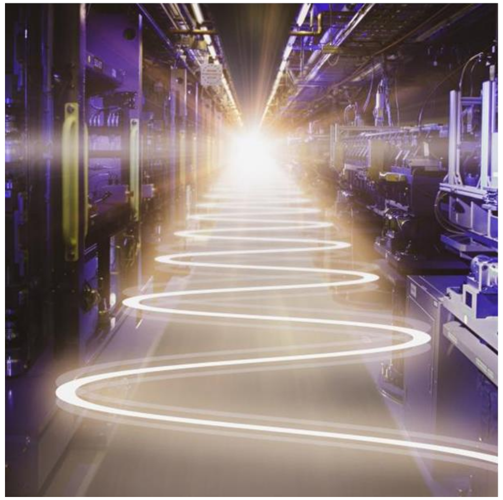
We live in exciting times for X-ray and neutron sources

- Set of world-leading upgrades in the user facility portfolio.
- Future projects will yet provide additional improvements in brightness, flux, coherence, repetition rate…
- Requires step-changes in instrumentation to generate and take advantage of gains.

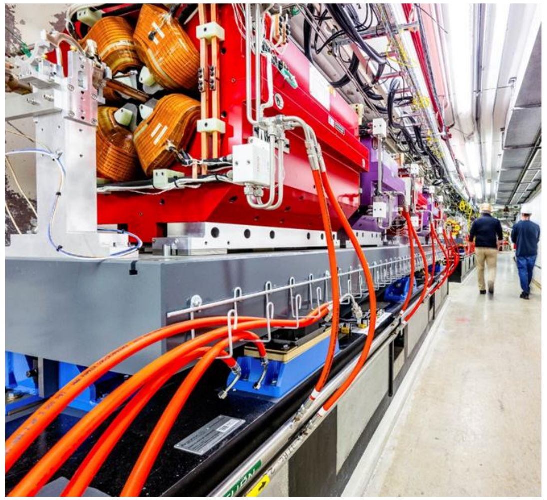
SNS-STS



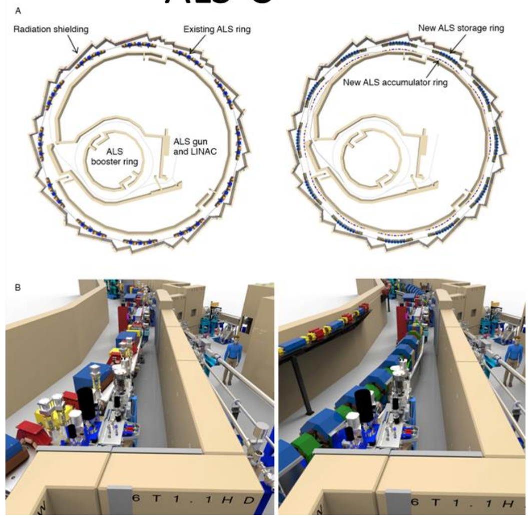
LCLS-II



APS-U



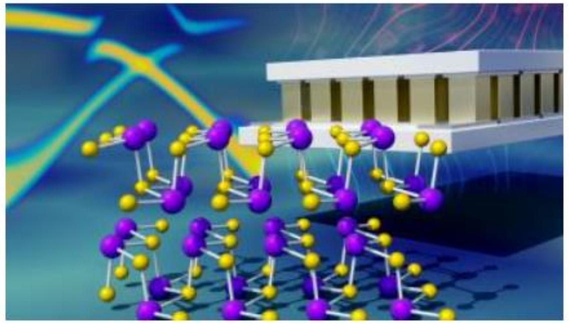
ALS-U



Research at BES User Facilities Impacts Many National Priorities: Energy, Electronics, Manufacturing, Health….

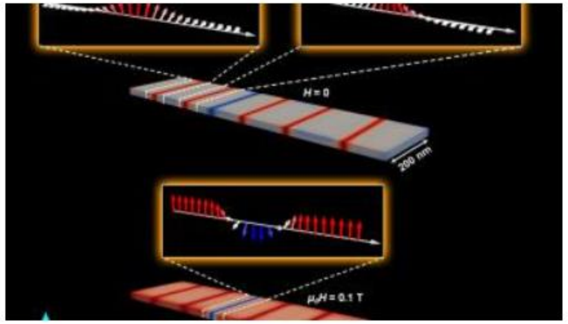
The Building Blocks for Exploring New Exotic States of Matter

Combining synthesis, characterization, and theory confirmed the exotic properties and structure of a new intrinsic ferromagnetic topological material.



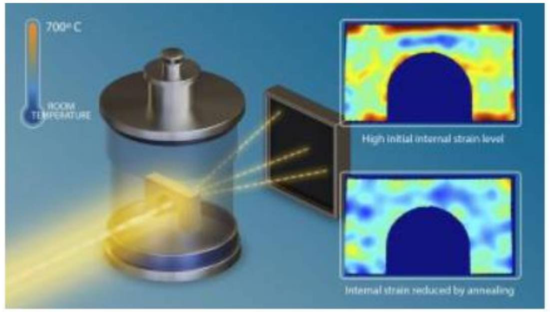
Uncovering the Atomic Mechanism Underpinning Heat Transport in Thermoelectric Materials

Neutrons reveal remarkable atomic behavior in thermoelectric materials for more efficient conversion of heat into electricity.



Scientists Take Control of Magnetism at the Microscopic Level

Studies of the nanostructure of a chiral magnet provides insights on controlling magnetic properties for applications in computers and other electronics.

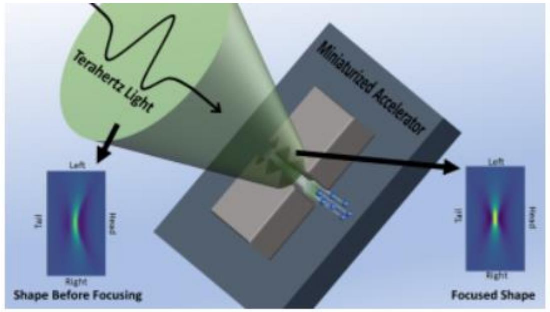


Real-Time Evaluation of Residual Strain Improves 3-D Printed Metal Parts

Neutron scattering monitors structures during post-production heat treatment to validate production models.

Real-Time Diagnostics for Better Engines

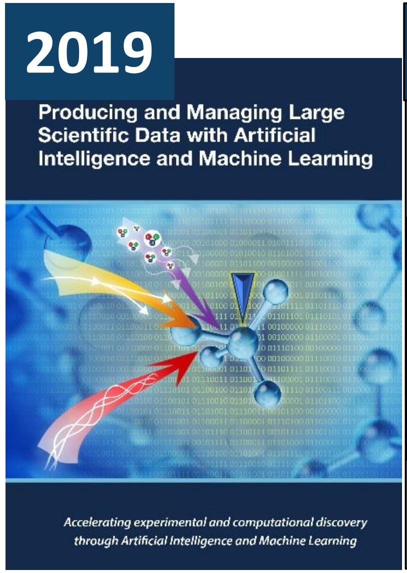
Scientists map atomic-level changes in the components of a running internal combustion engine using neutron techniques.

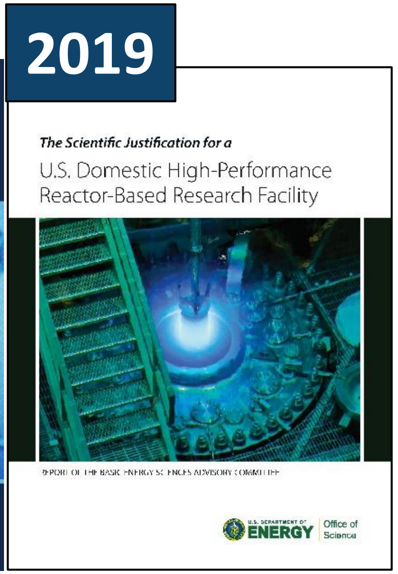


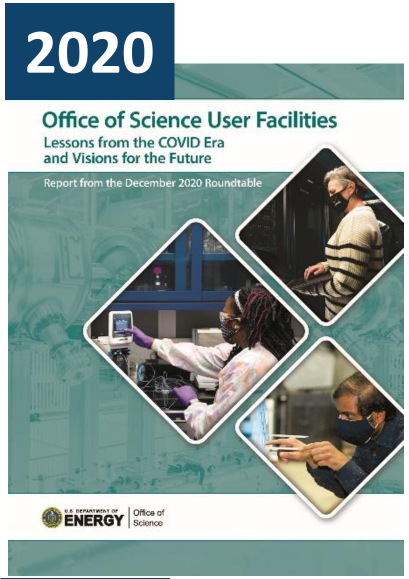
Sizing Up Special Light to Downsize Particle Accelerators

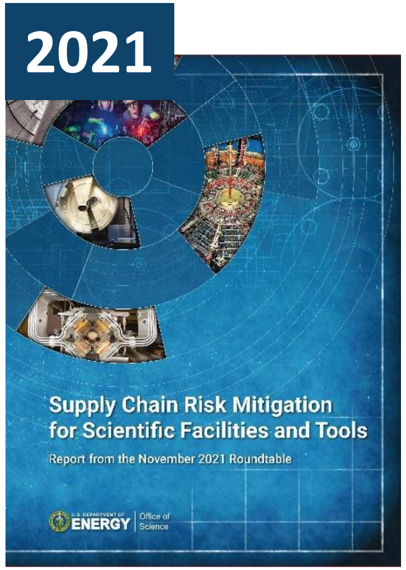
Measuring the shape of intense bursts of terahertz light paves the way for future accelerator technologies.

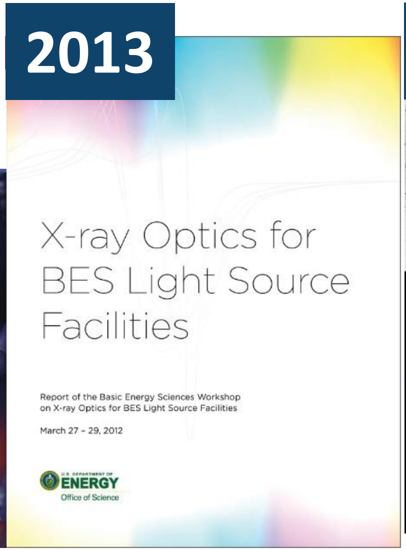
Roundtables and workshops

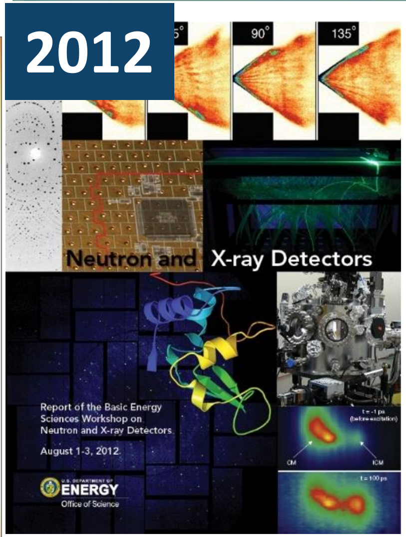


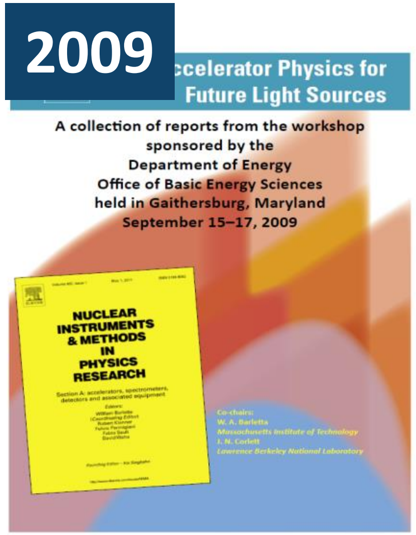












- Over the last 20 years, BRN Workshops have identified many scientific priorities in support of DOE's mission

- Many workshops and roundtables directly related to Office of Science "scattering" facilities

- This BRN provides PRDs* over a range of key enabling-fields for instrumentation

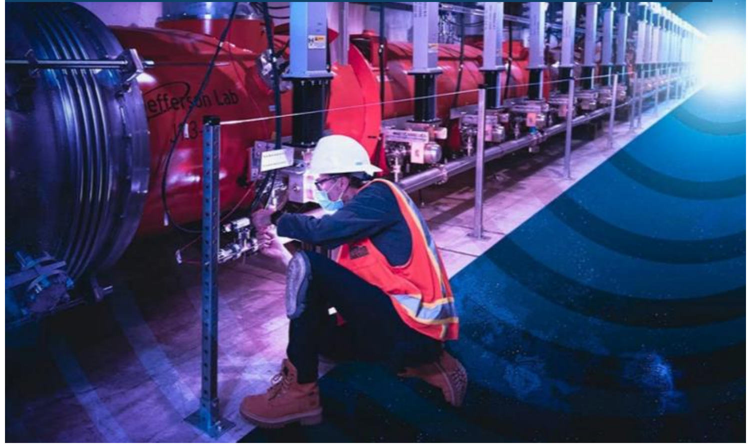
**PRD: Priority Research Direction*

BRN on Accelerator-Based Instrumentation

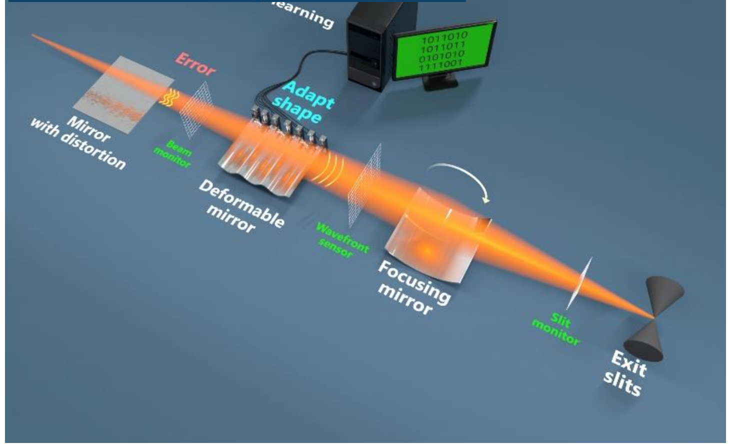
- Accelerator-based light sources and pulsed neutron sources
- Enabling instrumentation for **accelerators, optics, and detectors** underpin the transformation of these facilities and lay the foundations for future ones, providing unique characterization tools to over 16,000 users.

Cross-cutting topics (system design, AI/ML, simulations…)

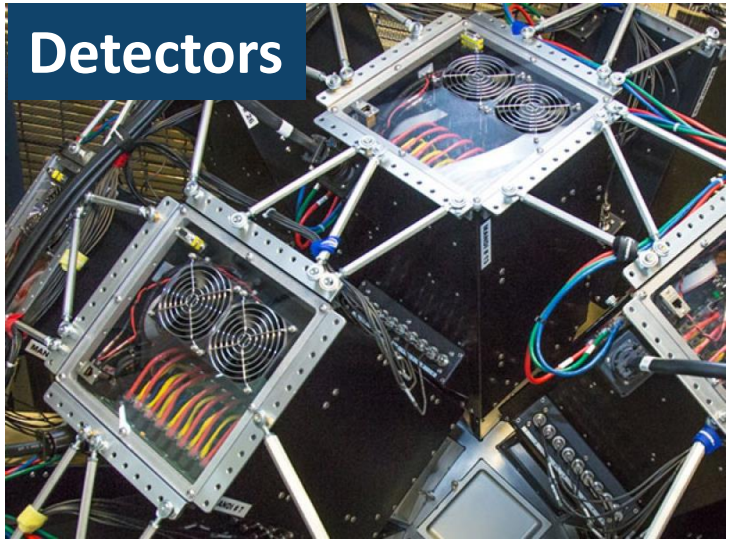
Accelerator components



Optical systems



Detectors



Workshop methodology

First Workshop

Virtual, Oct 19-20

All participants

A two-day workshop to identify the key drivers for the transformation of accelerator-based technologies. Initial Quad Charts developed.

- 4 plenary presentations
- Various contributed talks

Second Workshop

Virtual, Dec 1

All participants

Consolidation of Quad Chart research themes into 5 PRDs.

Identification of key questions and thrusts in each PRD.

Close-out

Virtual, Dec 11

Chairs and co-leads

Review of final PRDs

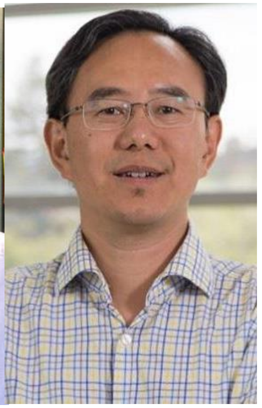
Discussion of report structure and writing assignments.

** An additional meeting for neutron optics was held separately (conflict with a NIST meeting limited participation)*

Panel Co-leads

Electron Accelerators

Timur Shaftan
BNL



Zhirong Huang
SLAC

Proton Accelerators

Fulvia Pilat
ORNL

Vladimir Shiltsev
Fermilab

Neutron Optics

Boris Khaykovich
MIT

Roger Pynn
Indiana Uni./UCSB

Cross-cutting

Jon Taylor
ORNL

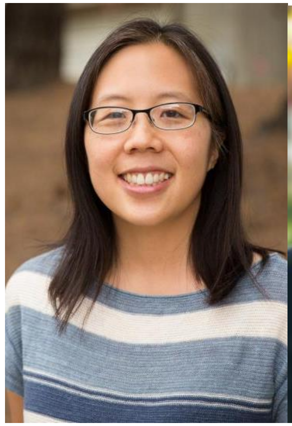
Daniel Ratner
SLAC

X-ray Detectors

Gabriella Carini
BNL

Peter Denes
LBNL

X-ray Optics

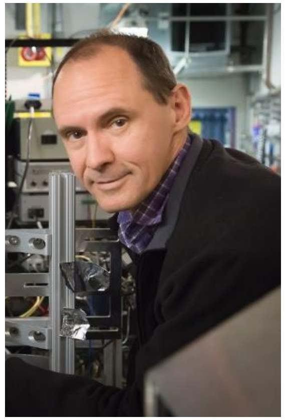


Anne Sakdinawat
SLAC

Lahsen Assoufid
ANL

Neutron Detectors

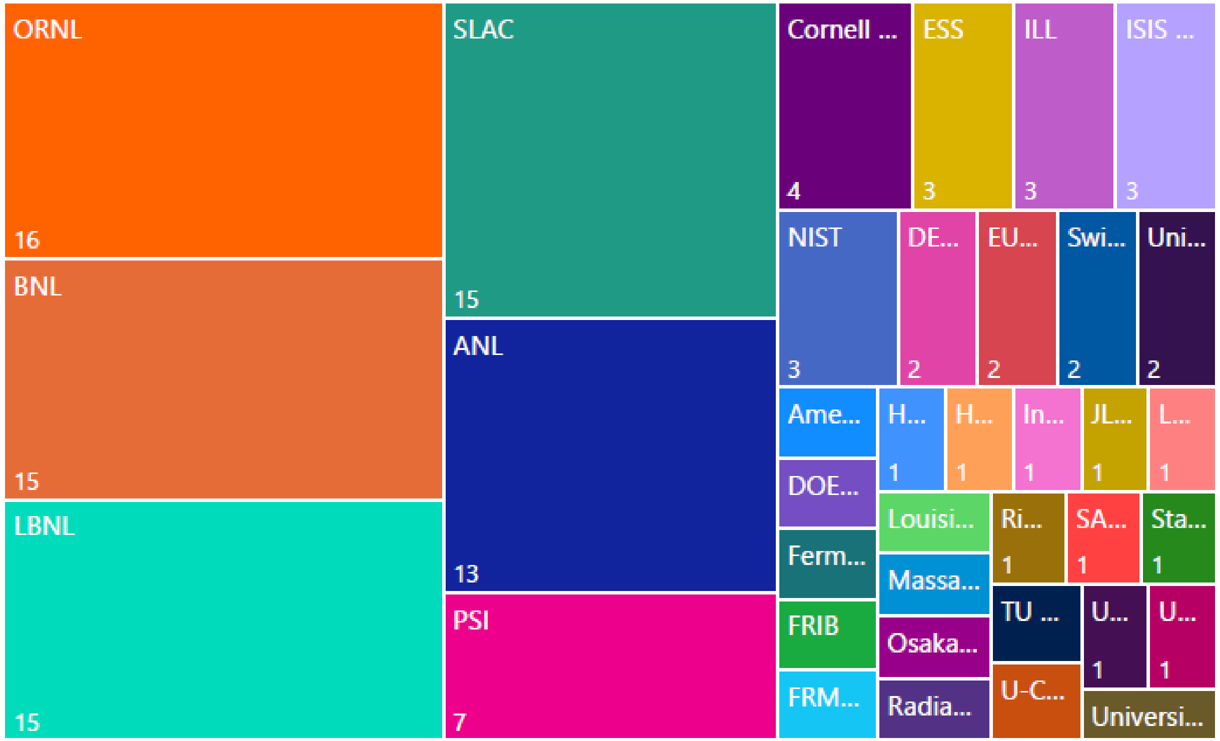
Anton Khaplanov
ORNL



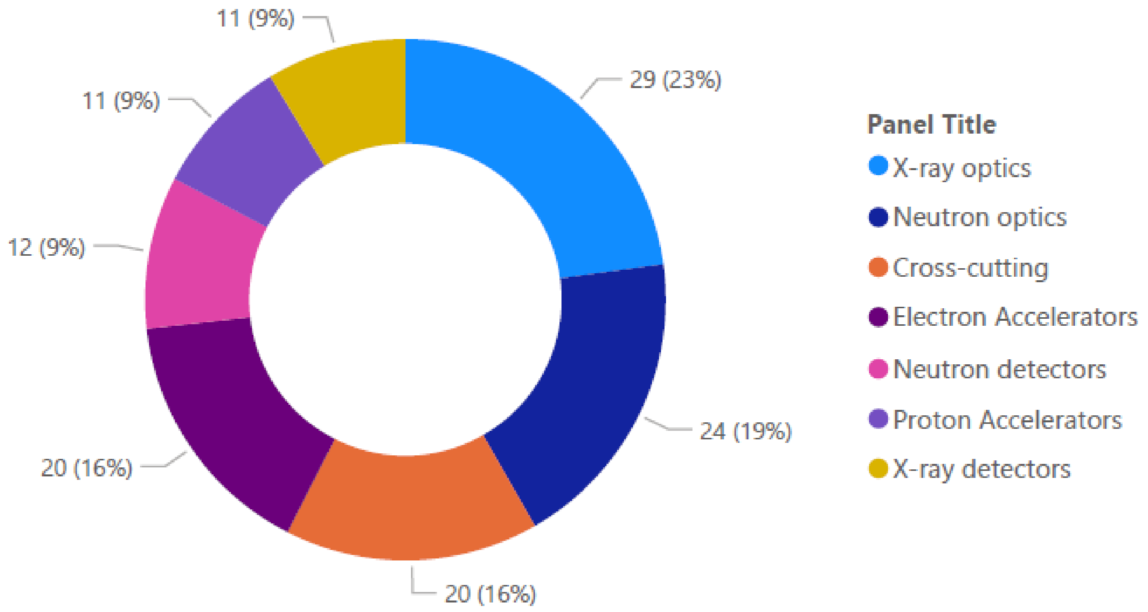
Anton Tremsin
UC Berkeley

Participation

Number of participants per organization



Participants per panel



- 14 co-leads
- 128 participants
- DOE labs, universities and 20% international
- 25 observers (BES and SC – NP, HEP, FES, BER… Offices)

Additional input to the BRN

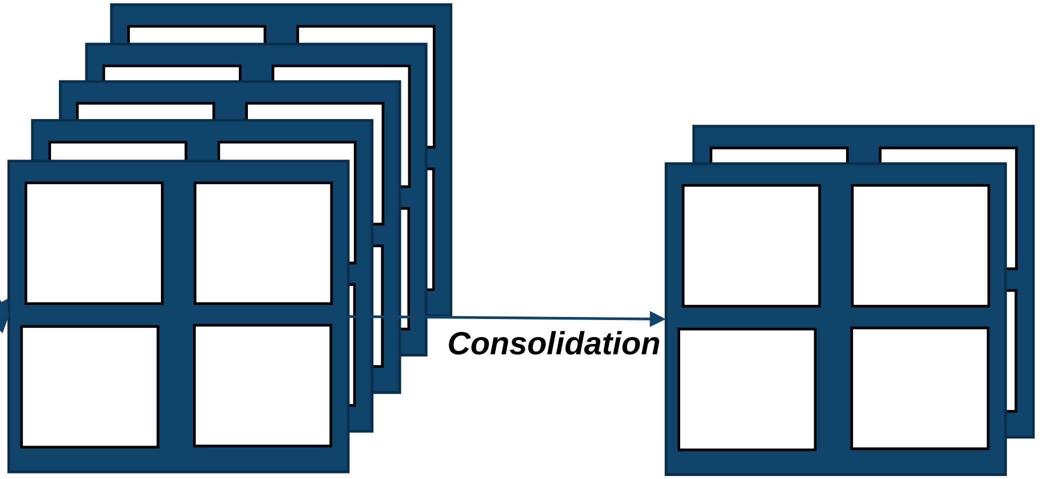
~150 participants, hybrid

Online survey

Pre-identified key themes as part of scope refining

- Plenaries
- Invited speakers
- Workshop discussion

Ideas generation



Quad Charts

Aggregated and curated Quad Charts

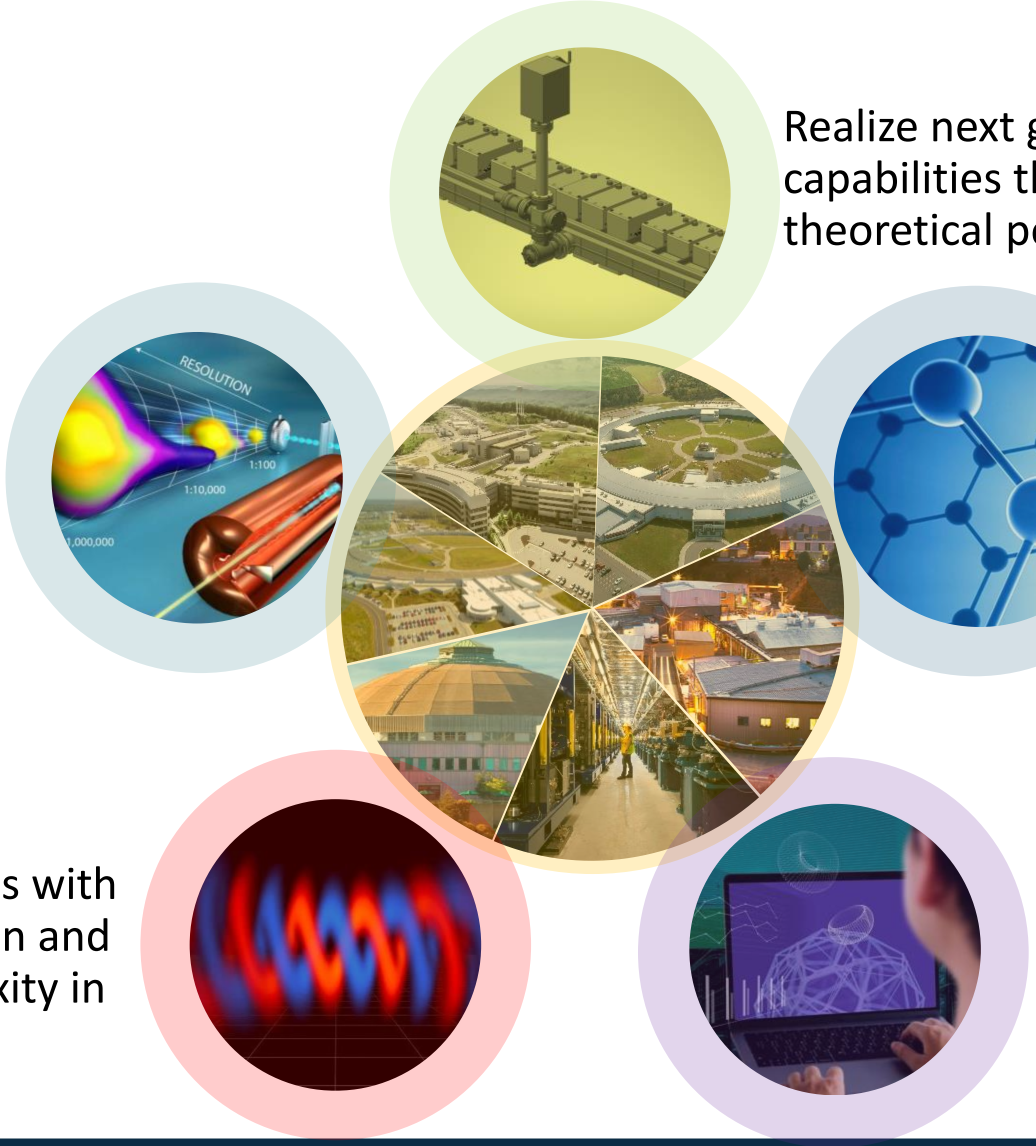
Day 1

Day 2

Priority Research Directions

Realize next generation capabilities that approach theoretical performance limits

Understand scientific mechanisms limiting system performance and utilization



Lead innovation in materials, design, and fabrication as a foundation for integration of technologies in accelerator-based facilities

Tailor and control beams with unprecedented precision and speed to probe complexity in matter

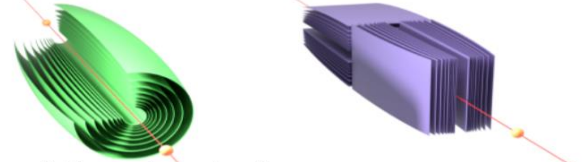
Accelerate progress with advanced modelling, real-time feedback, co-design and physical-digital fusion

Realize next generation capabilities that approach theoretical performance limits

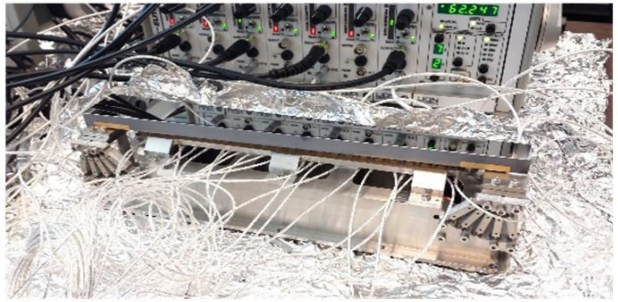
- **Key questions**: What research areas show the most promise in incorporating recent technological innovations or breakthroughs to offer new capabilities at accelerator-based facilities? Which innovations should be adopted to provide a competitive advantage?

Progress in high-power and high-brilliance sources is driven by research into new fabrication techniques, new materials, innovation in high-power electronics, lasers, optics, detectors and diagnostics. It is vital to provide a realistic path to the implementation of innovative concepts for technologies at accelerator-based facilities.

Advanced optics for optimal photon and neutron transport

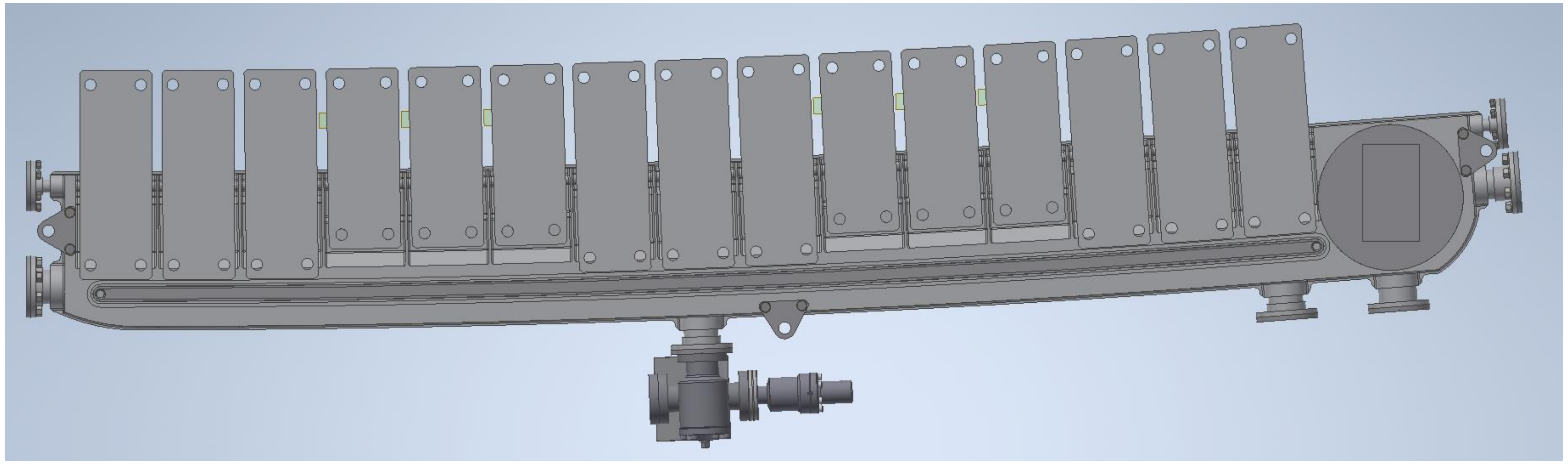


a) Nested optics for neutrons transport.



b) Adaptive X-ray mirror with highly controllable shape.

Ultra-compact lattice of mixed function magnets for next generation storage rings

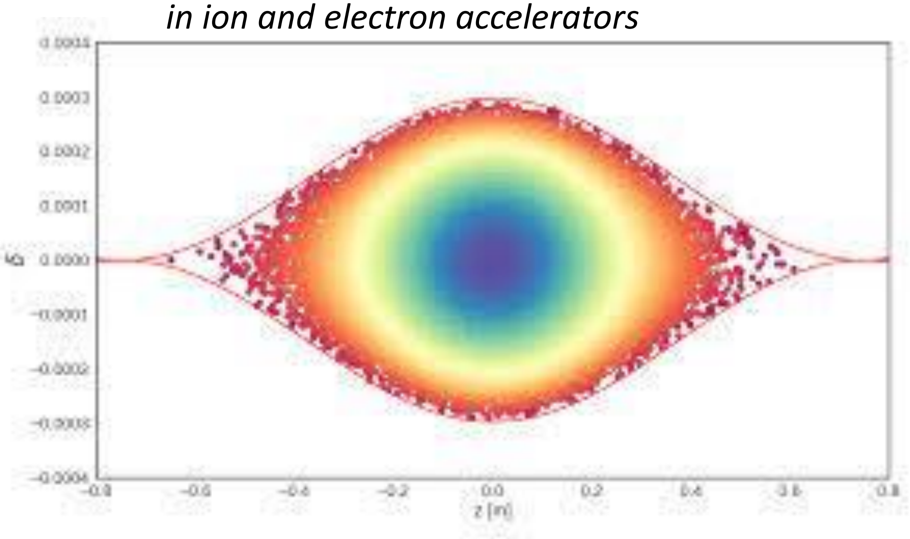


Understand scientific mechanisms limiting system performance and utilization

- **Key questions:** What are the key phenomena hindering step-changes in capabilities at accelerator-based facilities?

Multiple factors place practical limit on the performance of key technologies used in accelerator-based facilities and require an in-depth understanding of the mechanisms at play, or a clear analytical formulation or the ability to compute realistic simulations of the system.

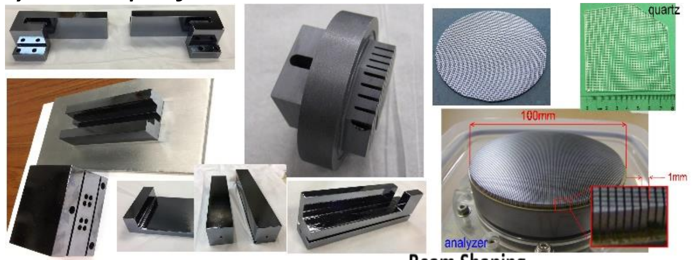
In-depth understanding of collective effects in ion and electron accelerators

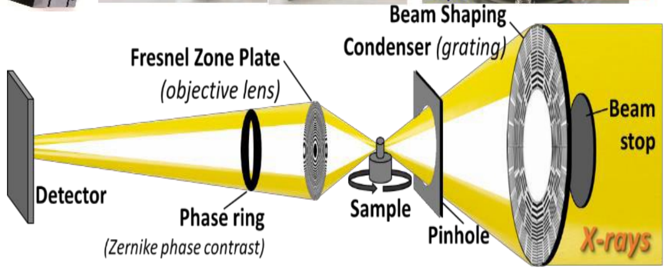


How do we achieve optimal detectors that approach multiple physical limitations

Source Improvement / Detector Improvement Needed	Brighter Sources	with better energy resolution	with better spatial resolution	with better temporal resolution
δT Speed	X	X	X	X
ε Efficiency	X	X	X	X
δE Resolution		X		
δt Time				X
Q Intensity	X		X	
δx Size		X	X	

Overcome materials, power loading, efficiency, and fabrication limitations in optical systems performance



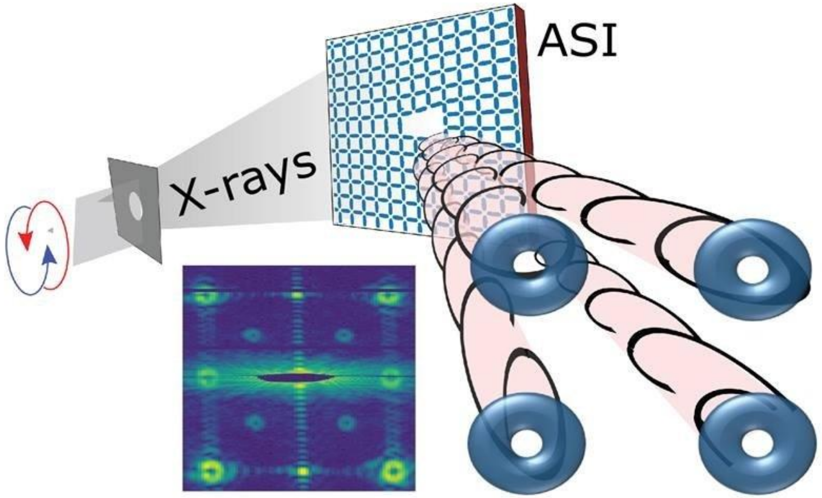


Tailor and control beams with unprecedented precision and speed to probe complexity in matter

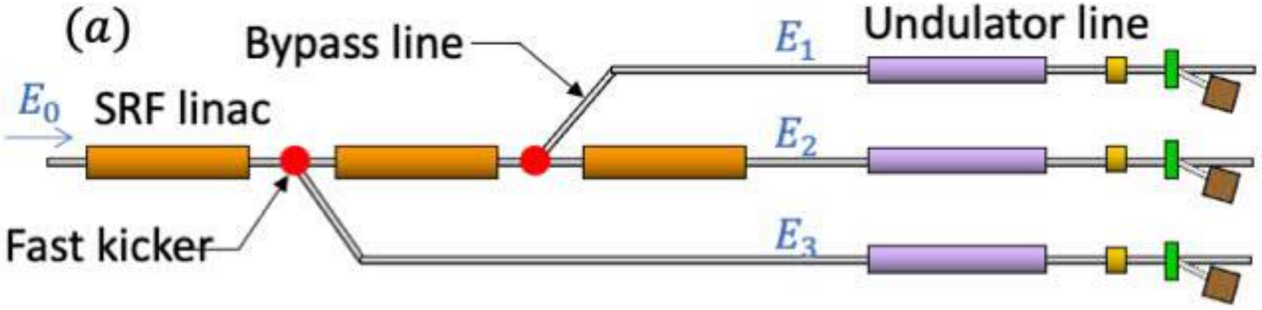
- **Key questions:** What are the most promising avenues to manipulate and multiplex beams to support a wide range of experiments in all research fields of the natural sciences?

Accelerator-based neutron and X-ray light sources are enabling more and more complex, often multi-modal, experiments in which the beam characteristics, i.e. size, shape, polarization are manipulated in real-time to probe materials and systems in a wide range of experimental conditions. Expanding the research capacity requires beam structuring and multiplexing.

How to create OAM or entangled neutron beams



How to multiplex XFEL beams

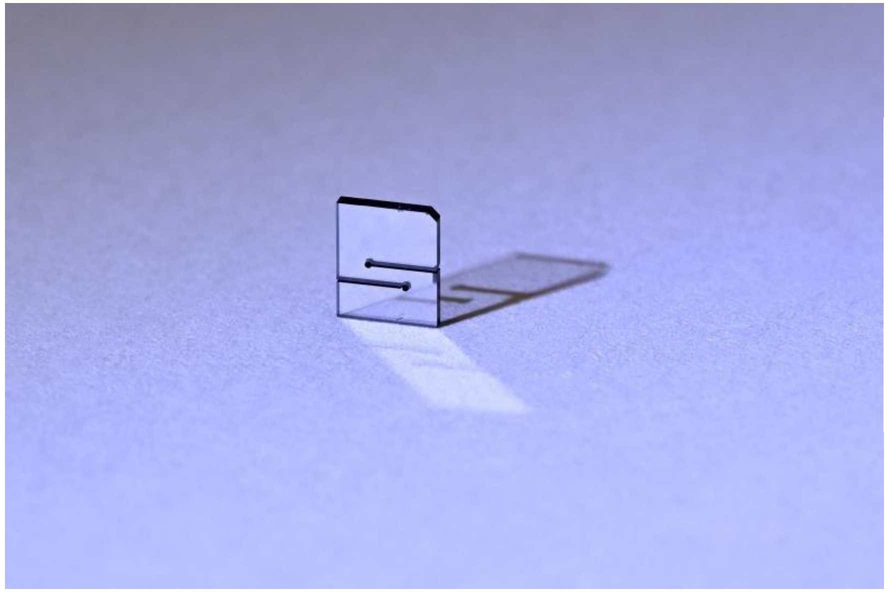


Lead innovation in materials, design, and fabrication as a foundation for integration of instrumentation for accelerator-based facilities

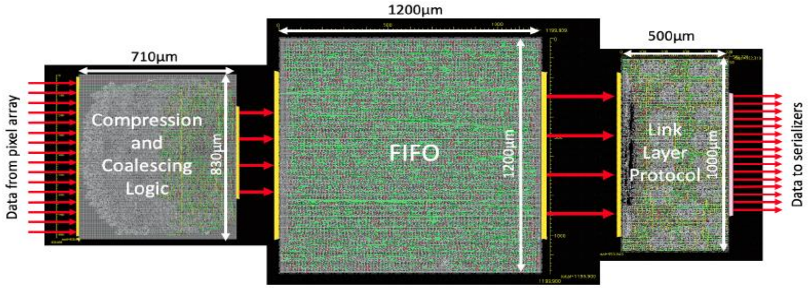
- **Key questions:** How can research in materials, advanced synthesis and manufacturing benefit accelerator instrumentation? Which critical technologies should be accelerated or de-risked by researching new methods, controlling supply, or enhancing the transfer of technologies?

From particle sources to optics and detectors, technologies for accelerator-based facilities rely heavily on new materials, new materials fabrication techniques, the control of properties from atomic to mesoscopic scales, advanced designs and manufacturing processes.

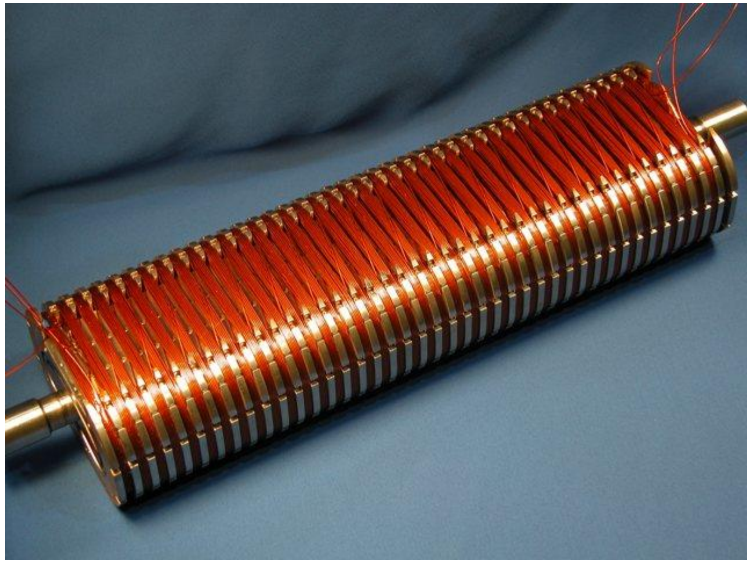
Diamond crystal mirror



ASIC
Semiconductor/advanced packaging



2nd gen. HTS tape for undulator



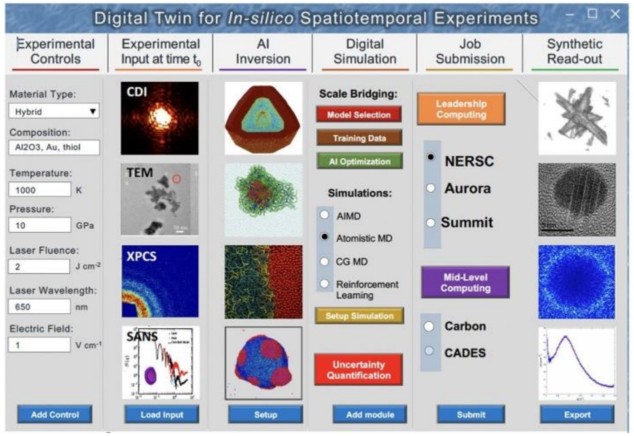
Accelerate progress with advanced modelling, real-time feedback, and physical-digital fusion

- **Key questions:** Can actionable, shareable digital twins that mimic real-life systems be developed to enhance the development and control of accelerator, optical, and detection systems? Where will the revolution in AI/ML and exascale computing transform the development of instrumentation for accelerator-based facilities?

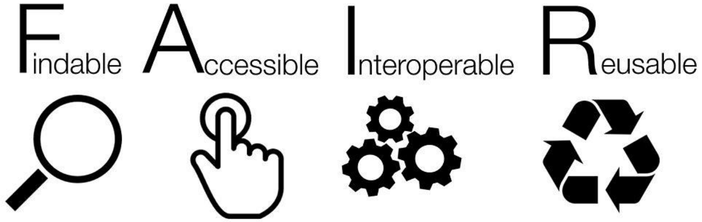
Advanced modelling of individual instrumentation components and systems including real-life systems, their digital representation and real-time integration, are becoming key to innovation and essential for increased operational efficiency of state-of-the-art facilities.

Advanced modelling capabilities

Modular digital twins



FAIR principles for ABI



Summary and next steps

- BRN Workshop addressed a wide-range of research needs in accelerator components, optics, detectors and cross-cutting themes
- BRN workshop generated wide community interest serving as an incubator for additional roundtables and facility discussions on more specialized topics
- BRN outcome will be discussed at Facility Directors' 6-way meeting in January 2024 (light sources +neutron sources).
- Brochure will be produced early in 2024
- BRN report due for publication by March 2024
- Research in advanced instrumentation is key to the development of existing facilities and an essential to define future facilities