IAEA
International Atomic Energy Agency

# Summary of the Working Group on AI for Nuclear Physics


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**Stefanie Reichert** *Springer Nature, Germany*
**Matteo Barbarino** *IAEA, Austria*


**Technical Meeting on Artificial Intelligence for Nuclear Technology and Applications**
#AI4Atoms Virtual Event
25–29 October 2021

IAEA
International Atomic Energy Agency

## Participants

Rick Archibald (ORNL, USA)
Yassid Ayyad (USC, Spain)
Rebecca Auchettl (ANSTO, Australia)
Maria Liz Crespo (ICTP, Italy)
Auralee Edelen (SLAC, USA)
Cristiano Fanelli (MIT, USA)
Morten Hjorth-Jensen (University of Oslo, Norway and MSU, USA)
Tzany Kokalova Wheldon (University of Birmingham, UK)
Dean Lee (MSU/FRIB, USA)
Witold Nazarewicz (MSU/FRIB, USA)
Yifei Niu (Lanzhou University, China)
Karin Rathsman (ESS, Sweden)
Alexander Scheinker (LANL, USA)
Tiago Silva (University of São Paulo, Brazil)
Gianluca Valentino (University of Malta, Malta)

# Nuclear Physics

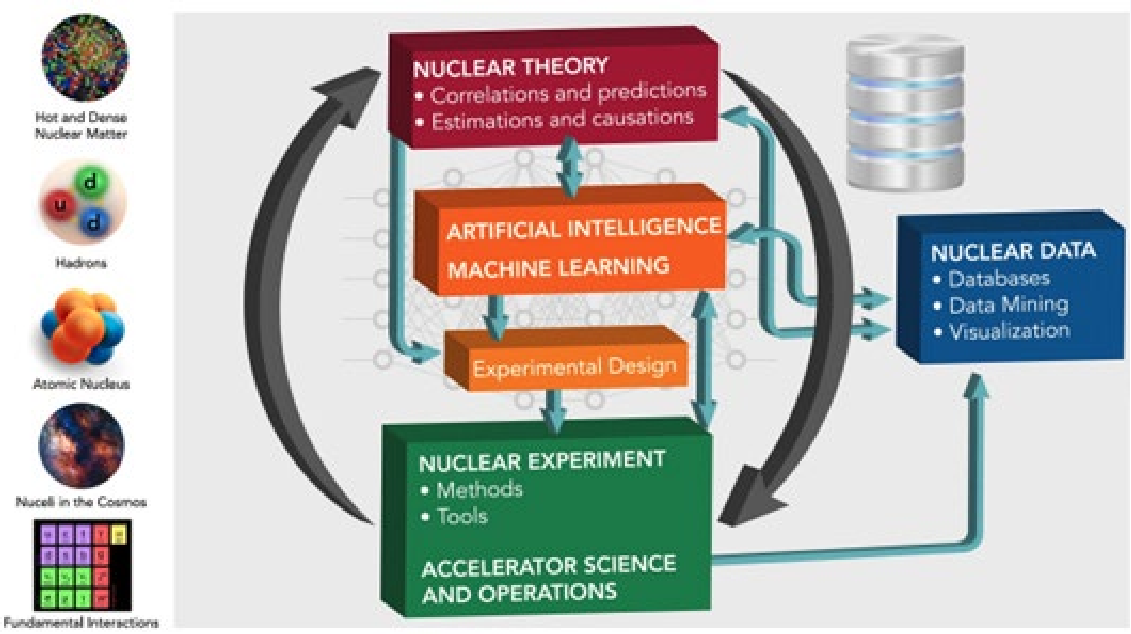



Image courtesy of W. Nazarewicz, FRIB, MSU, USA

# Nuclear Physics

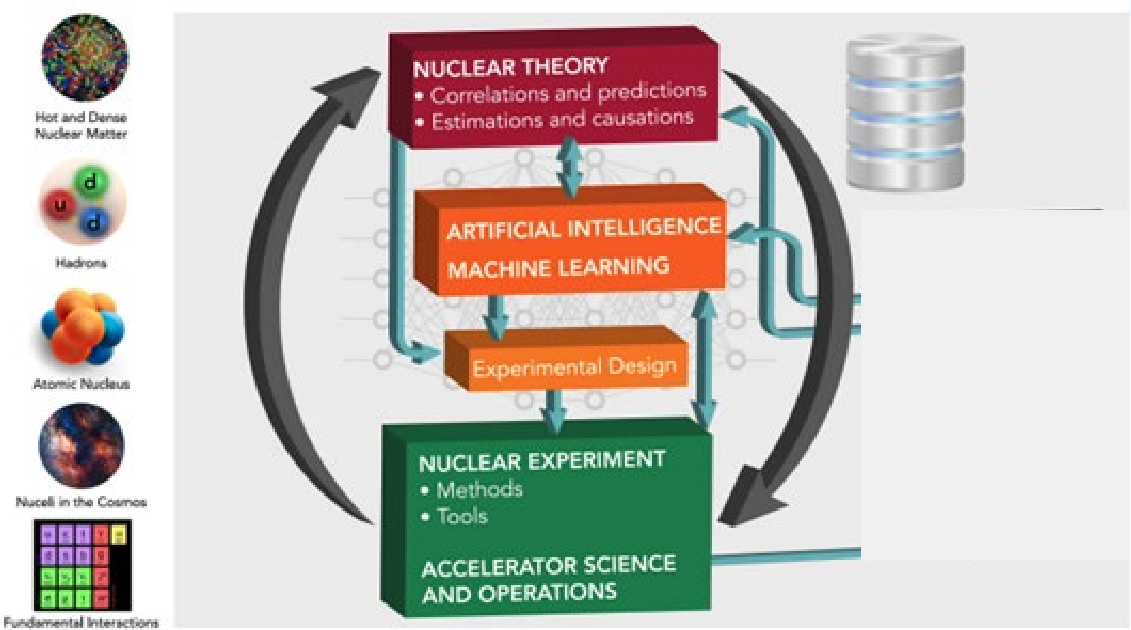
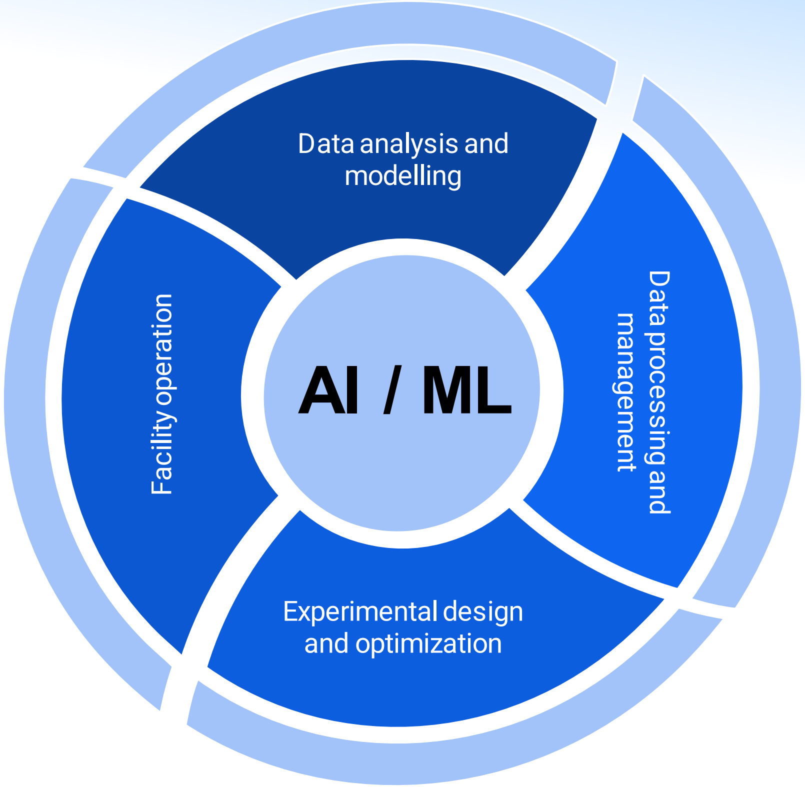



Image courtesy of W. Nazarewicz, FRIB, MSU, USA

# AI in Nuclear Physics

- Analysis and Modeling
- Data Processing and Management
- Experimental Design and Optimization
- Facility Operation



# State of the Art / Ongoing Efforts

# Analysis & Modeling

## ML in nuclear theory

Bayesian model averaging, see L. Neufcourt et al., Phys. Rev. Lett. 122, 062502 (2019)

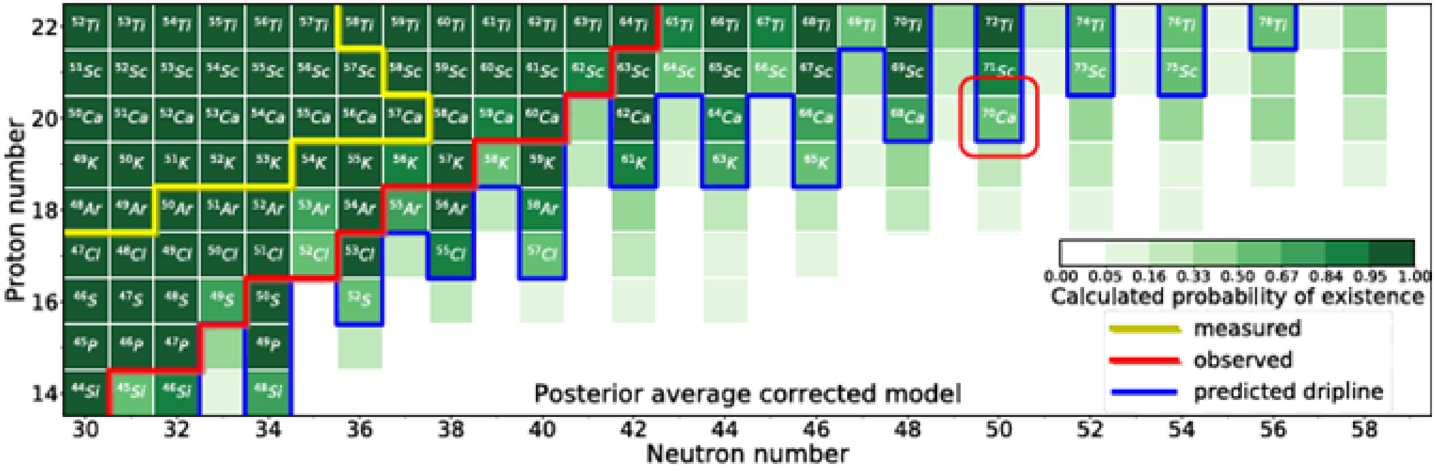
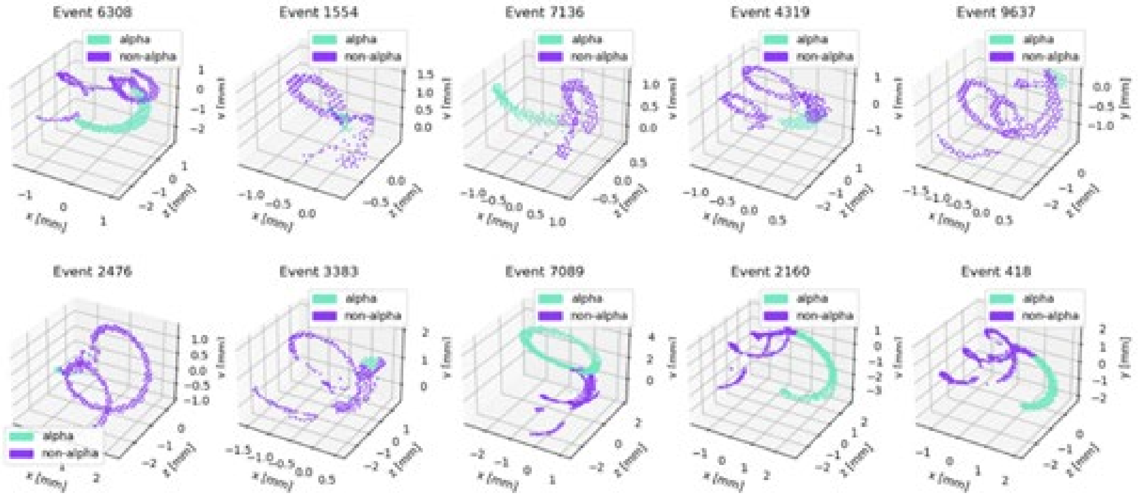



Image courtesy of W. Nazarewicz, FRIB, MSU, USA

# Data Processing and Management

## ML for event and particle identification



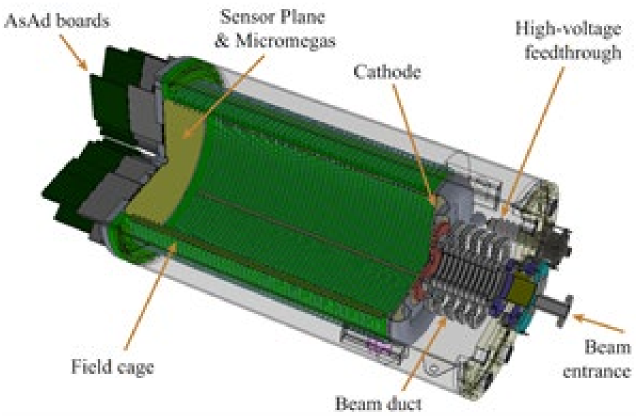
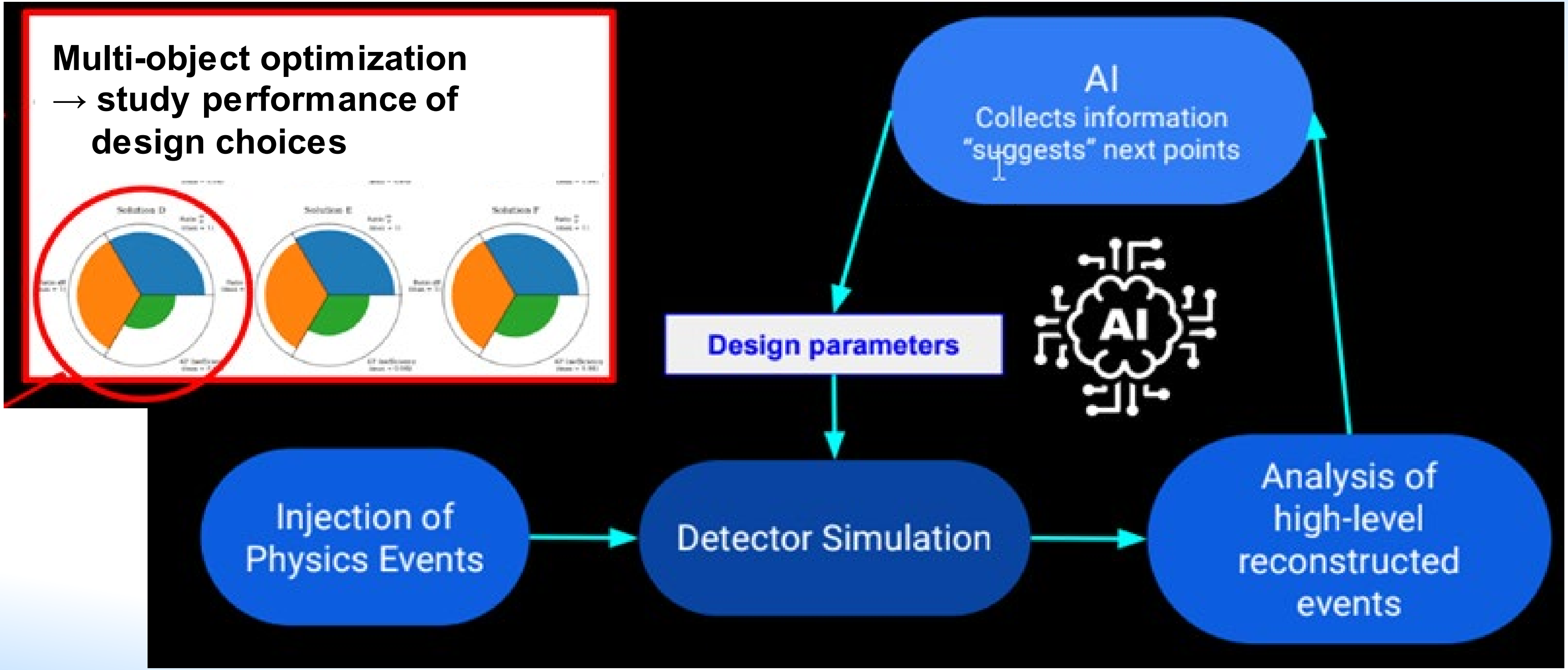




Image courtesy of Y. Ayyad, USC, Spain

# Experimental Design
## ML for experimental design

Image courtesy of C. Fanelli, MIT, USA



# Facility Operation

## ML in accelerator operation

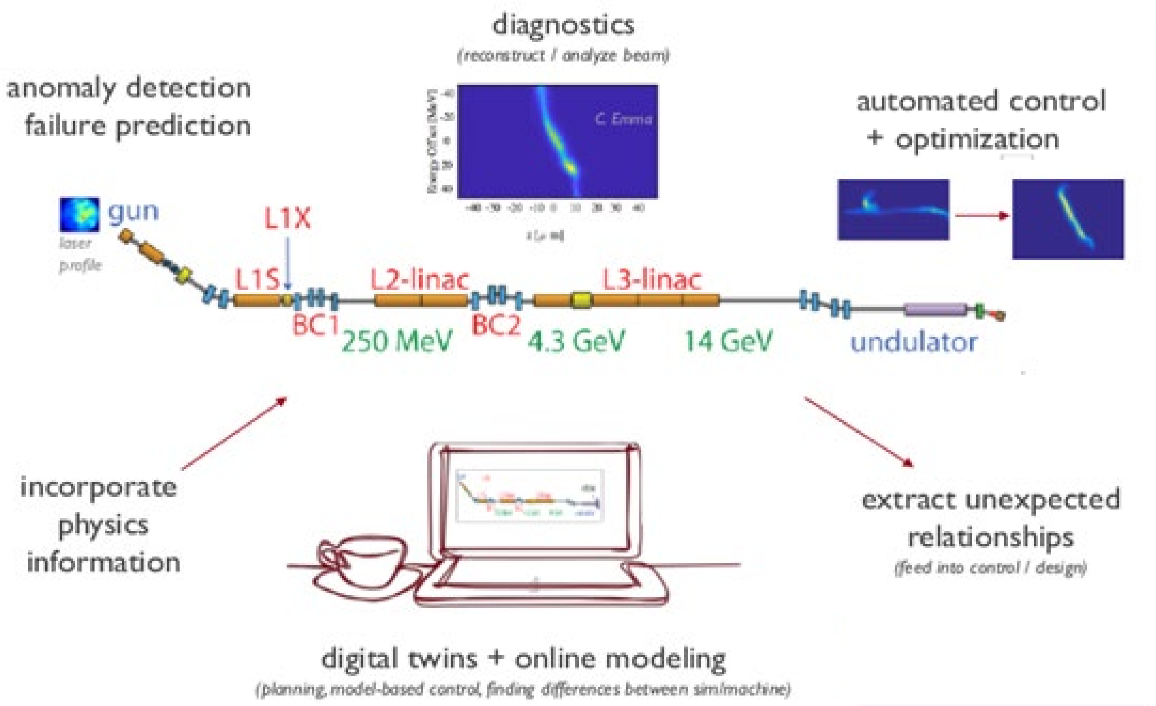
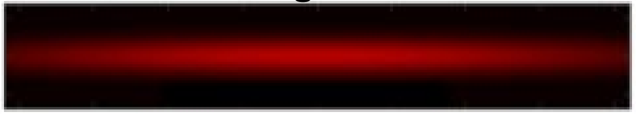



Image courtesy of A. Edelen, SLAC, USA

# Facility Operation
## ML in accelerator operation

**Starting beam**



**AI-informed beam design**

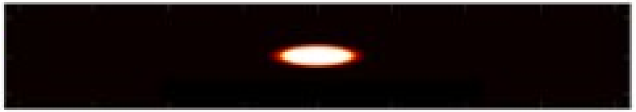
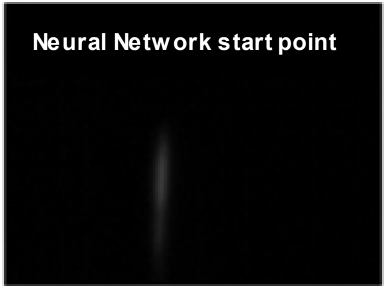
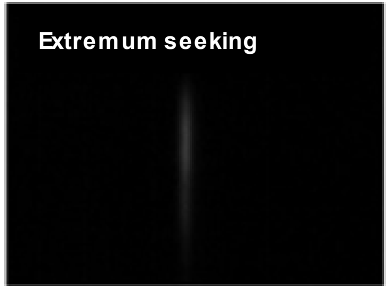
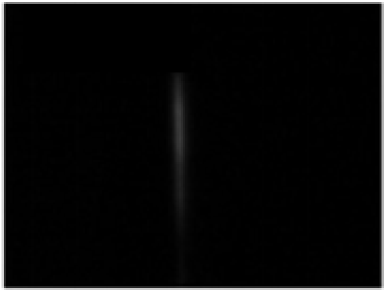


Image courtesy of R. Auchettl, ANSTO, Australia







**Machine-learning-based tuning in seconds**

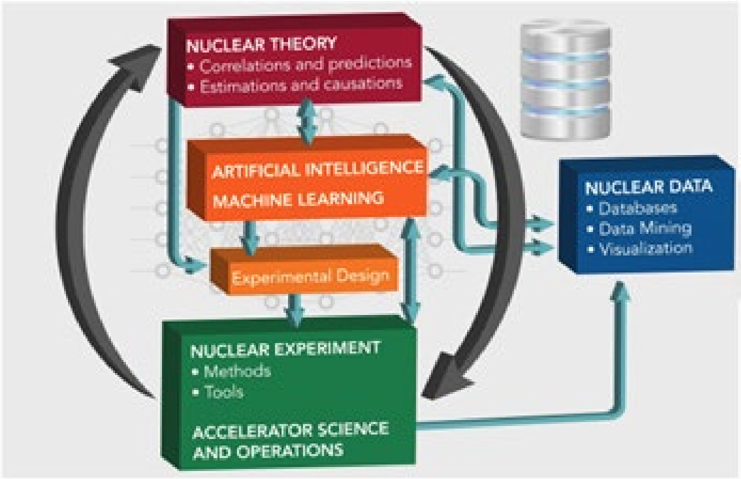
**Hand tuning by expert in 10–20 min**

Image courtesy of A. Edelen, SLAC, USA

# Cross-cutting Needs and Next Steps

# Cross-cutting Needs

- Nuclear Science Drivers
  - Real-time systems
  - Uncertainty quantification in AI
- Education efforts
  - AI-focused summer schools and workshops
- Interdisciplinary funding
  - Positions
  - Research & Development
  - Production/deployment efforts



# Cross-cutting Needs

Ongoing

- Nuclear Science Drivers
  - Real-time systems
  - Uncertainty quantification in AI

Next steps

- Education efforts
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  - Positions
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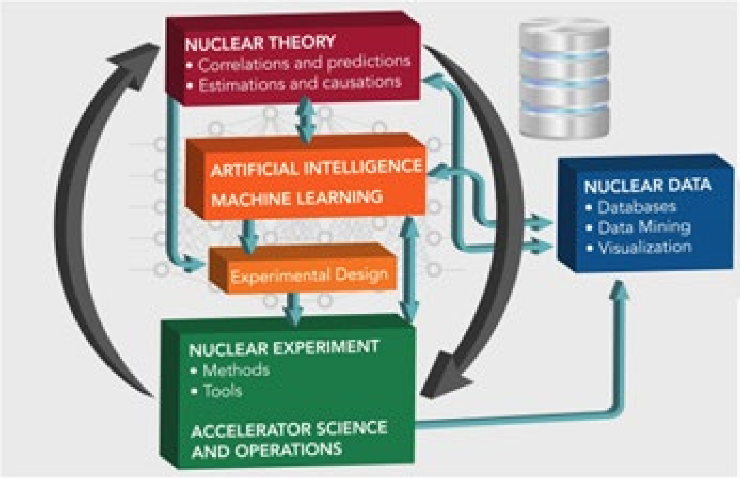
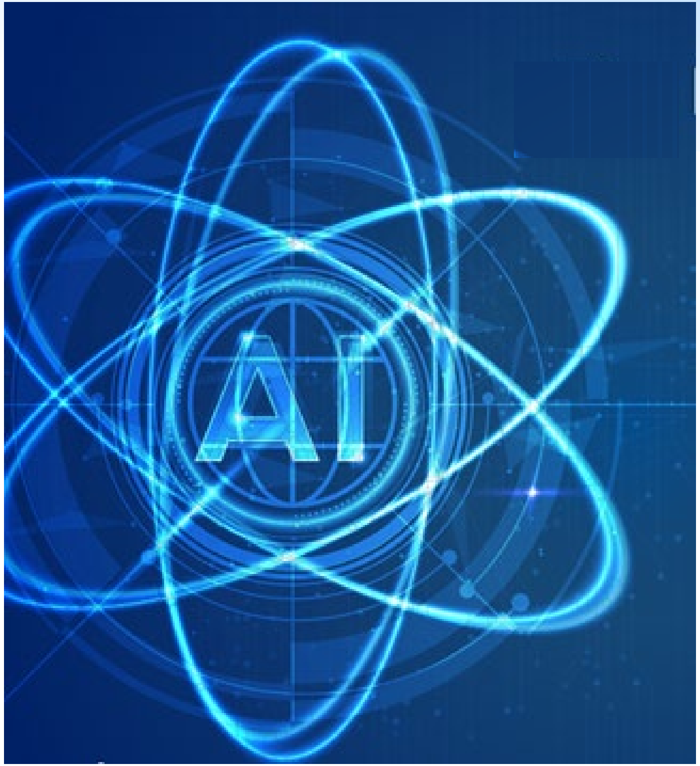


# Accelerating Progress—IAEA's Role

IAEA

- Nuclear Science Drivers
    - Real-time systems
    - Uncertainty quantification in AI
- Sponsorship of community efforts
    - Data challenges / hackathons
    - Online resource center
        - Living review of AI in nuclear physics
        - Nuclear physics- based benchmarks
        - Datasets
        - Event listing
- Workforce development
    - Established summer schools
    - Internships and fellowships
- Interdisciplinary coordination
    - Networks
    - Coordinated research activities
    - Standards on non-expert controlled research



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**Real-time optimization at AWAKE**

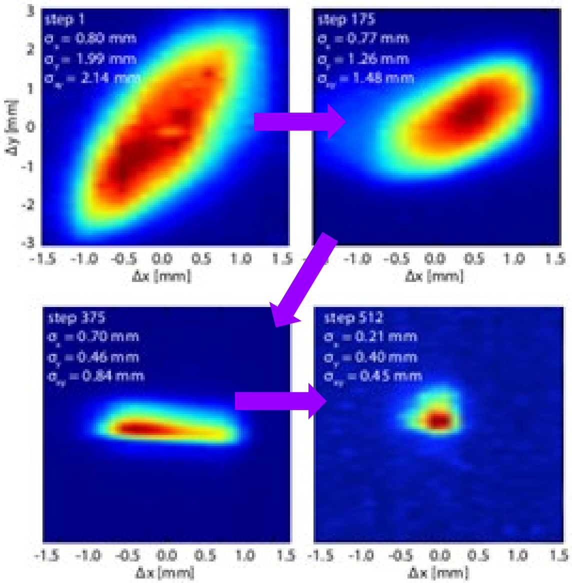


Image courtesy of A. Scheinker, LANL, USA

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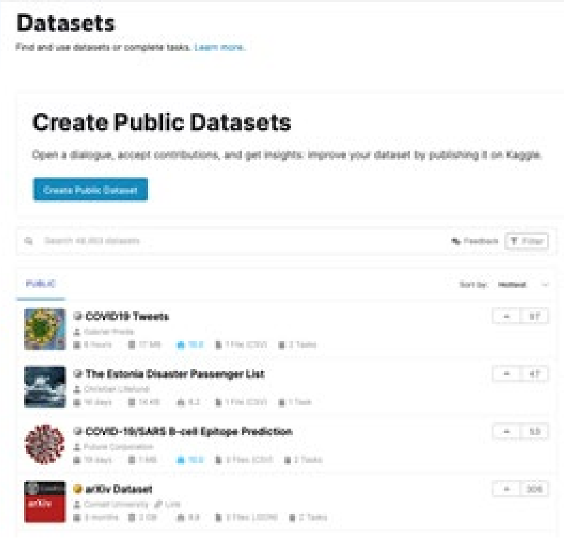


IAEA DATA VISUALIZATION CHALLENGE

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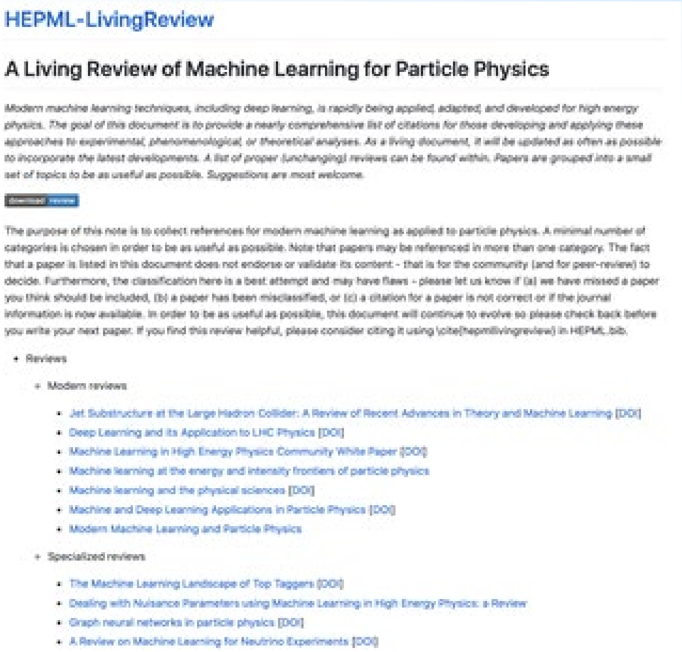

HEPML-LivingReview

A Living Review of Machine Learning for Particle Physics

*Modern machine learning techniques, including deep learning, is rapidly being applied, adapted, and developed for high energy physics. The goal of this document is to provide a nearly comprehensive list of citations for those developing and applying these approaches to experimental, phenomenological, or theoretical analyses. As a living document, it will be updated as often as possible to incorporate the latest developments. A list of proper (unchanging) reviews can be found within. Papers are grouped into a small set of topics to be as useful as possible. Suggestions are most welcome.*

The purpose of this note is to collect references for modern machine learning as applied to particle physics. A minimal number of categories is chosen in order to be as useful as possible. Note that papers may be referenced in more than one category. The fact that a paper is listed in this document does not endorse or validate its content - that is for the community (and for peer-review) to decide. Furthermore, the classification here is a best attempt and may have flaws - please let us know if (a) we have missed a paper you think should be included, (b) a paper has been misclassified, or (c) a citation for a paper is not correct or if the journal information is now available. In order to be as useful as possible, this document will continue to evolve so please check back before you write your next paper. If you find this review helpful, please consider citing it using \cite{hepmllivingreview} in HEPML.bib.

- Reviews
  - Modern reviews
    - Jet Substructure at the Large Hadron Collider: A Review of Recent Advances in Theory and Machine Learning [DOI]
    - Deep Learning and its Application to LHC Physics [DOI]
    - Machine Learning in High Energy Physics Community White Paper [DOI]
    - Machine learning at the energy and intensity frontiers of particle physics
    - Machine learning and the physical sciences [DOI]
    - Machine and Deep Learning Applications in Particle Physics [DOI]
    - Modern Machine Learning and Particle Physics
  - Specialized reviews
    - The Machine Learning Landscape of Top Taggers [DOI]
    - Dealing with Nuisance Parameters using Machine Learning in High Energy Physics: a Review
    - Graph neural networks in particle physics [DOI]
    - A Review on Machine Learning for Neutrino Experiments [DOI]

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Theory Alliance
FACILITY FOR RARE ISOTOPE BEAMS


INSTITUTE for
NUCLEAR THEORY

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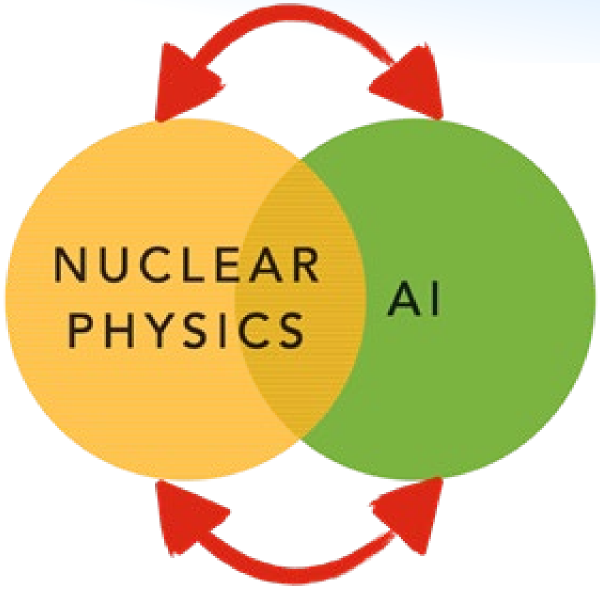

# Expected Outcomes

IAEA

- Acceleration of scientific discovery
- Standards for non-export controlled research
- Workforce development
- More high-quality data
- Data standards
- Easier access to information
- Improved beam quality
- Common reporting standards
- Engagement with adjacent fields
- Increased beamtime / more experiments
- Reproducibility

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*Thank you!*