NERSC: A Critical Resource for Nuclear Physics Research Program

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Large-Scale, High-Performance Computing: essential to critical progress in Nuclear Physics

NP Mission:

discover, explore, and understand all forms of nuclear strongly interacting matter.

Fundamental degrees of freedom: quarks and gluons

Color confinement, not directly observable

Dynamics of quarks and gluons: Quantum Chromodynamics (QCD) , a non-abelian gauge theory

Nuclear matter phenomena: large range of length and energy scale

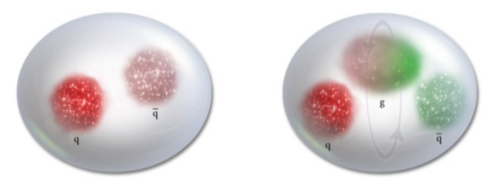
HPC --- essential in understanding nuclear matter and establishing predictive capabilities, enabling progress in new frontier

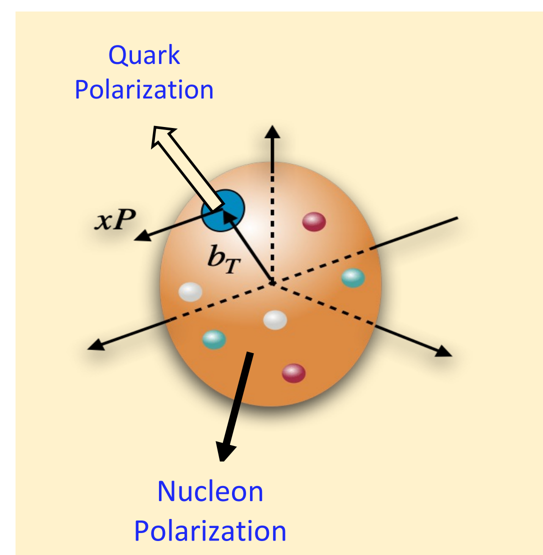
HPC – critical for transformational progress in nuclear physics across all NP sub-areas

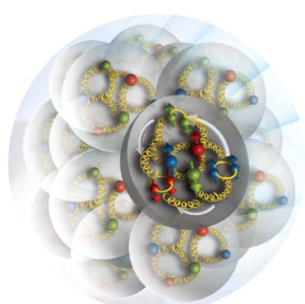
Cold QCD: precise theoretical calculations of properties of mesons, nucleons, light nuclei based on QCD, enabling accurate predictions

Example:

- *Hadron spectroscopy and exotic states of quarks and gluons*
- *Generalized Parton Distributions, gluonic structure of nucleons and nuclei, gluon contribution to mass, spin of nucleons and nuclei*

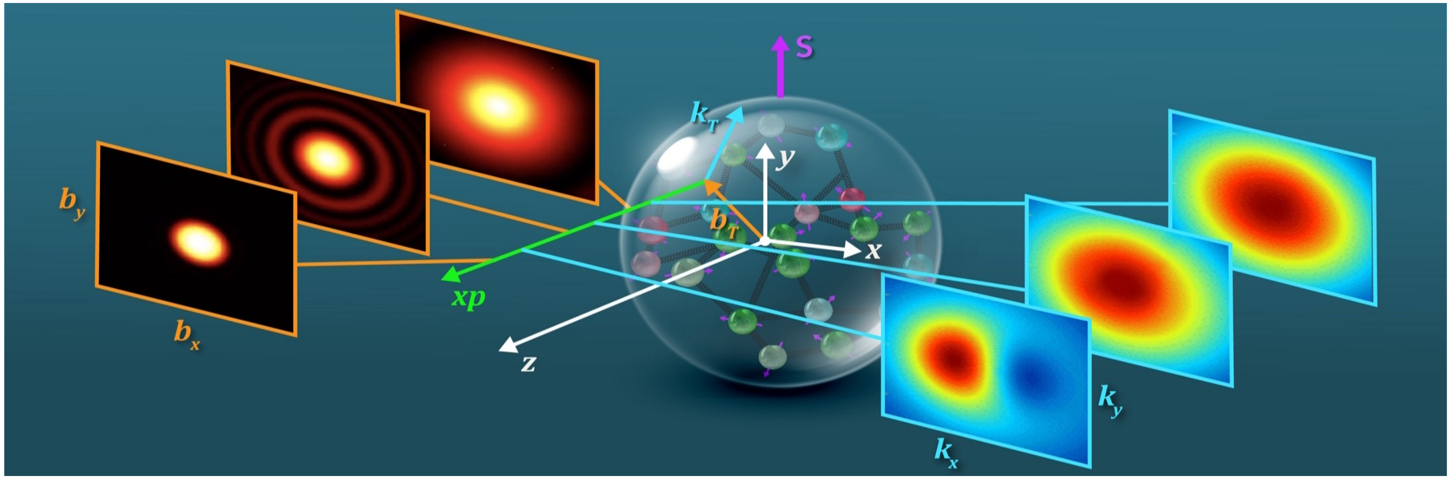






HPC enables progress in new science frontier

Example : Nucleon structure and Femto-scale 3-D imaging of nucleons

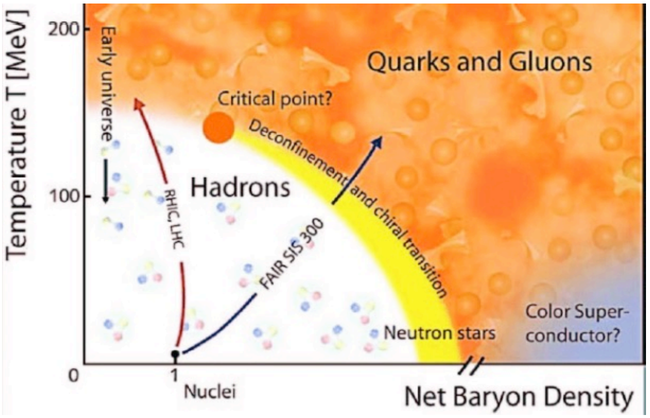


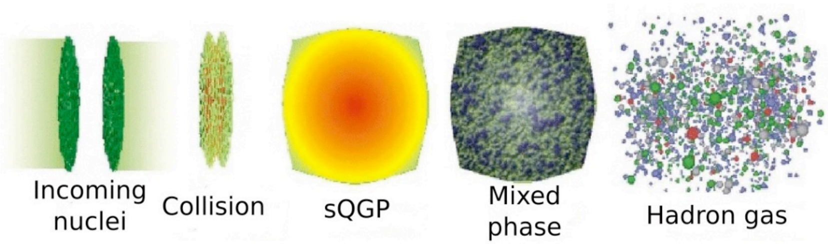
Needs to extract multi-dimensional Quantum Correlation Functions of quarks and gluons from a vast amount of experiment data in high energy nuclear collisions at Jlab and future EIC

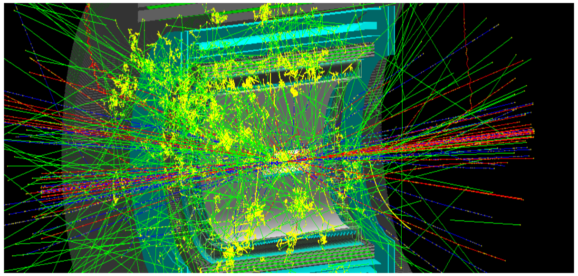
Hot QCD
numerical calculations for nuclear matter under extreme conditions: hot and dense nuclear matter, QGP the early universe, explosive astrophysical events, neutron stars

Example:

- *Extracting Properties of Quark-gluon Plasma (QGP): initial conditions in heavy-ion collisions, jet tomography*
- *Establishing QCD phase diagram and critical point*
- *Medium properties of QGP*



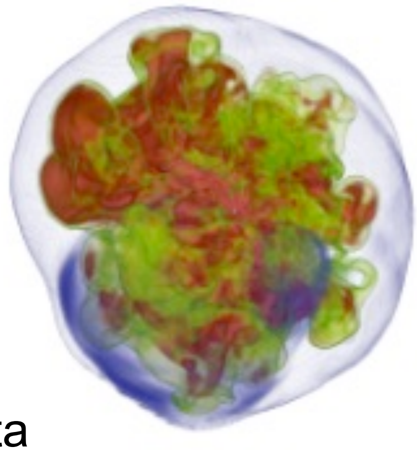




Nuclear Astrophysics:

Example:

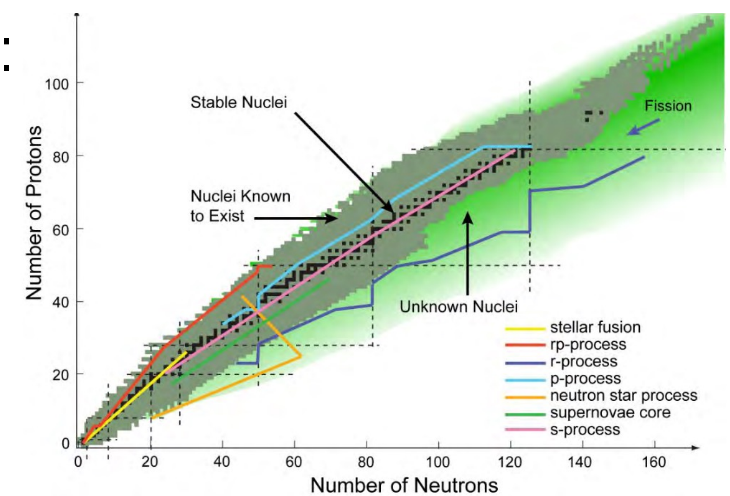
- understanding origin of heavy elements from astrophysical processes such as r-process, simulations of neutron star mergers, core collapse of supernovae



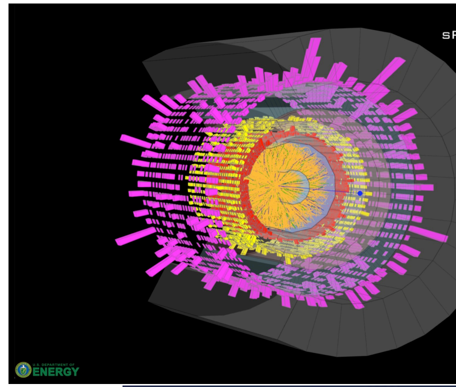
- Multi-messenger nuclear astrophysics: combine data from astrophysics observations, LIGO, heavy ion collisions and other laboratory experiments to constrain nuclear EoS and understand the neutron rich matters

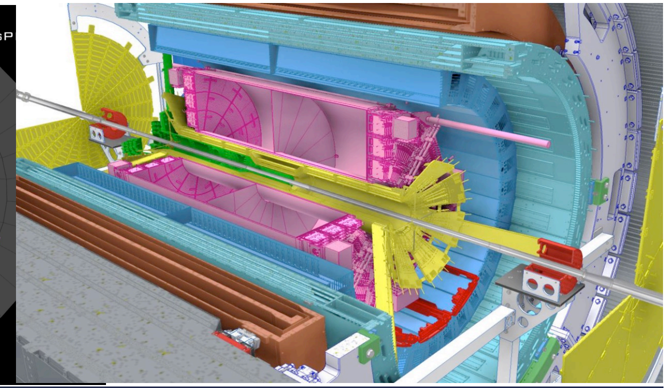
Nuclear Structure and Reactions:

Examples: Ab initio computations of nuclei and nuclear properties across the nuclear chart for their spectra, transition rates, energies; nucleon reactions; neutrino interactions in nuclei



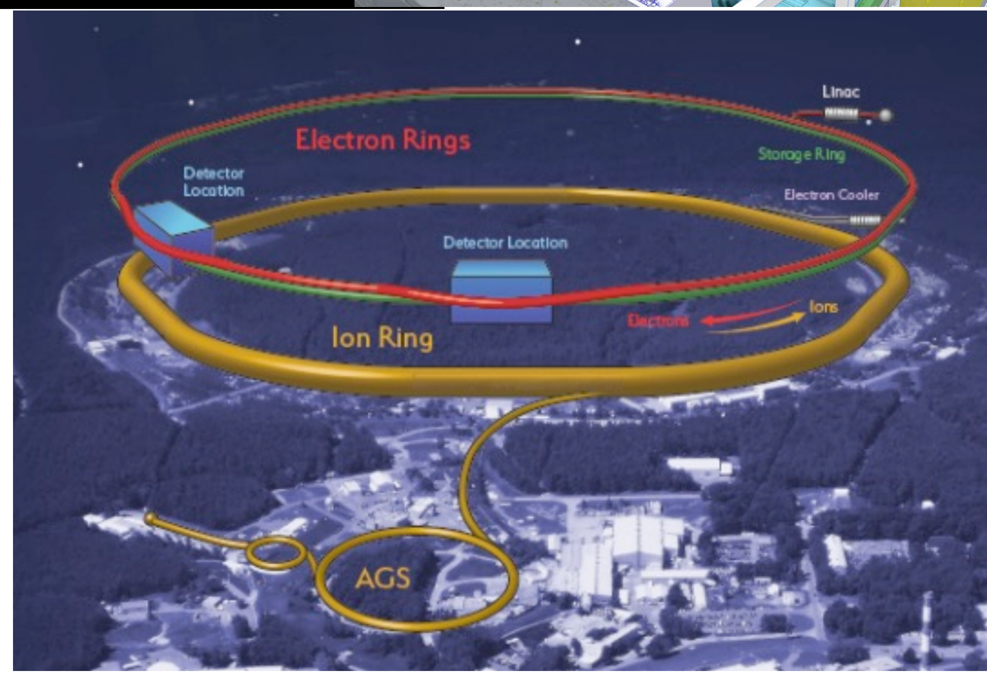
Experiment: Data analysis, Detector simulations, Accelerator simulations





Examples:

- *Analysis and Simulation for the GlueX Detector*
- *STAR Detector Simulations and Data Analysis*
- *Data analysis and simulations for the ALICE experiment at the LHC*
- *RHIC sPHENIX experiment*
- *Next generation NP accelerator: Electron-Ion Collider*



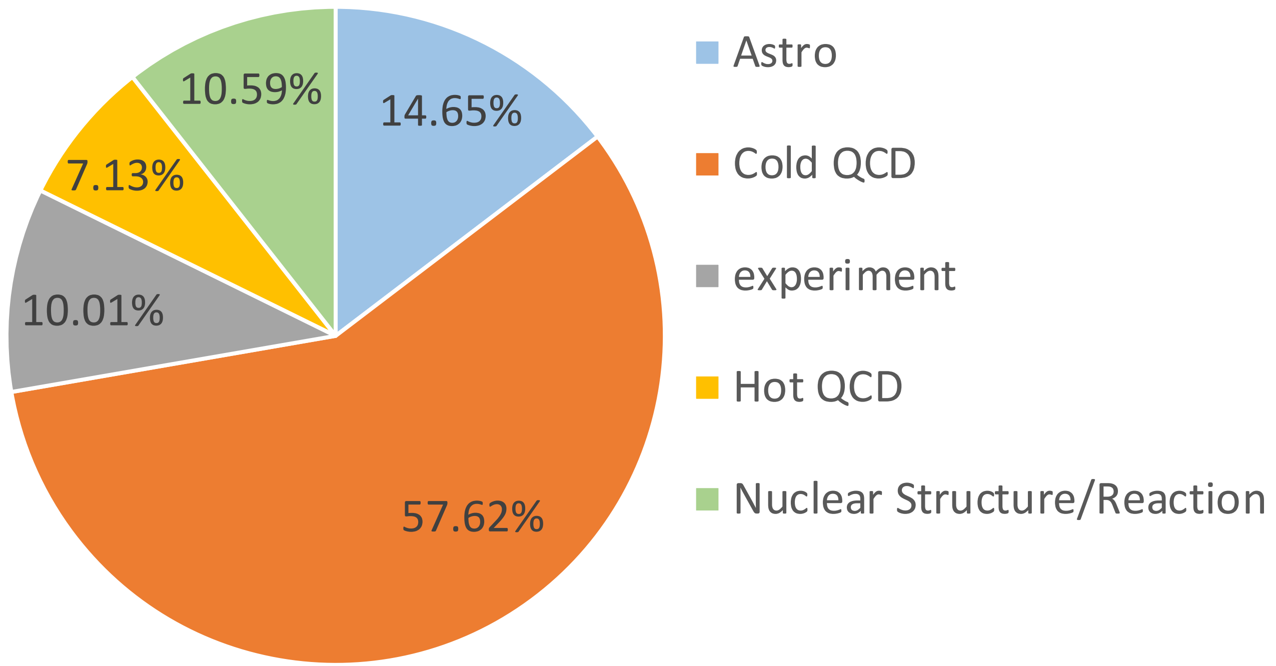
AI and Machine Learning for NP: opportunity to transform NP

Examples:

- Experiment: real-time analysis and feed back; improved simulation and data analysis
- Extraction of physical observables: great promise in tackling inverse problems of understanding hadron structure from first principle
- Global analysis of experiment data: enabling the development of new tools to advance the science of nuclear femtography and 3D nucleon imaging
- Computations of heavy nuclei based on realistic two- and three-nucleon interactions with full uncertainty quantification
- Neutron star and dense matter equation of state: improving simulation

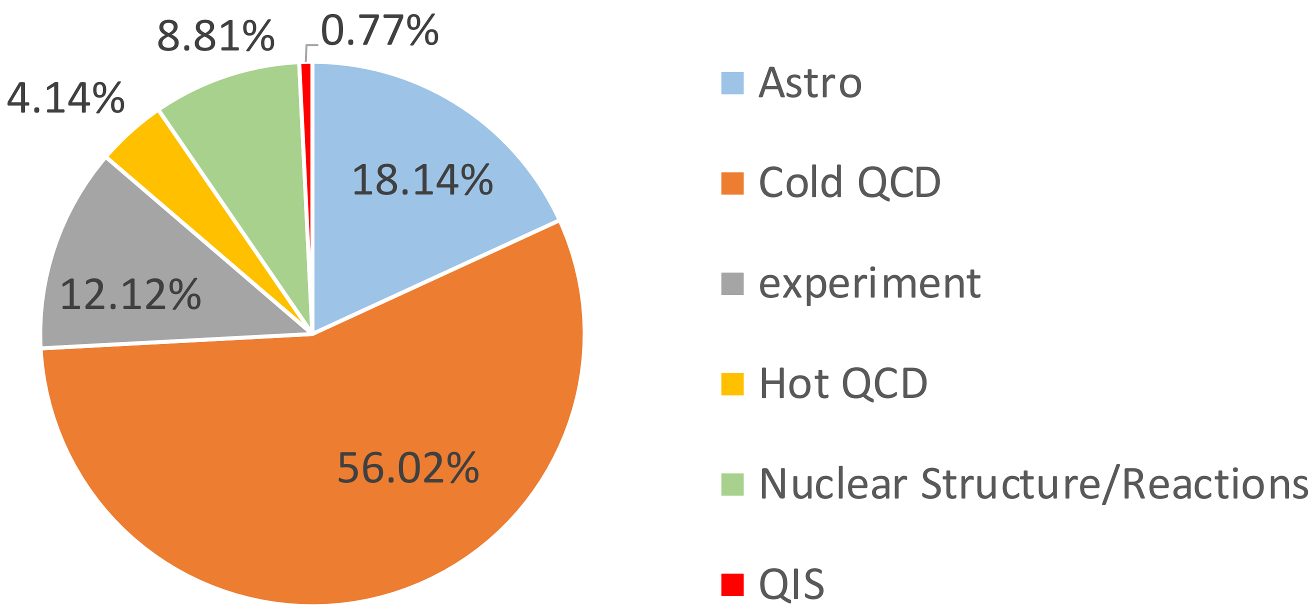
Hight light: replacing nuclear reaction computational kernels by ML effort to significantly speed up the time-to-solution of nuclear reactions in simulating astrophysical hydrodynamics phenomena in supernovae (SciDAC TEAMS)

2021 NP CPU hours requests



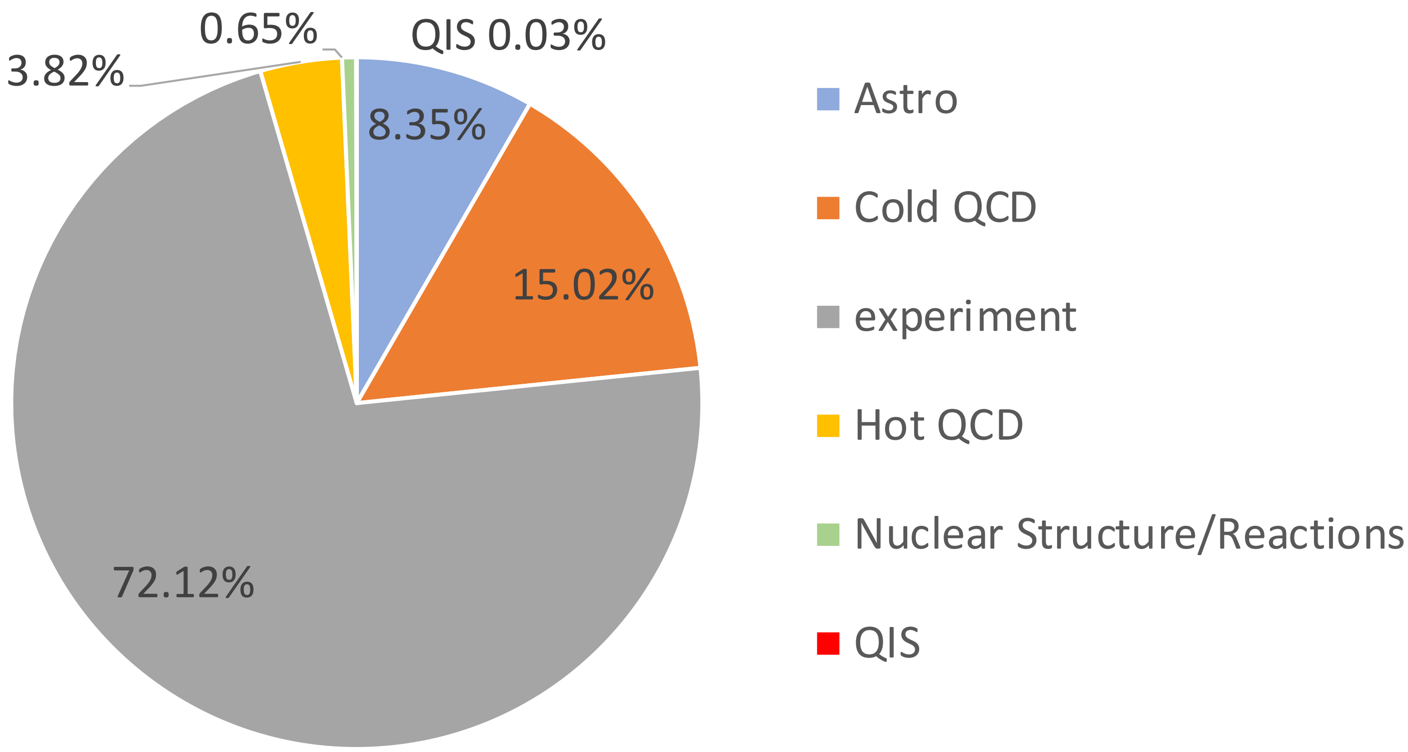
Requested hours = 2.34 times of total NP reserve

2022 NP CPU hours requests



Requested hours = 4.46 times of total NP reserve

2022 NP GPU hours requests



Requested hours = 16 times of total NP reserve

- *NERSC is a essential resource for Nuclear Physics Research Program across all subfields*
- *NP projects and research groups depends on NERSC allocation*
- *NP has large demands for NERSC allocation*

And the demands are growing