Nuclear Physics with High Performance Computing

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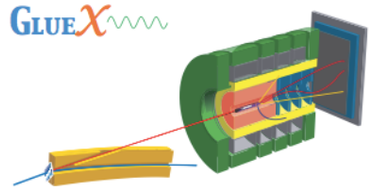
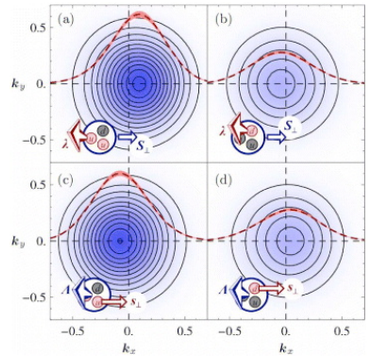
LQCD/NP Science & connection to Expt.

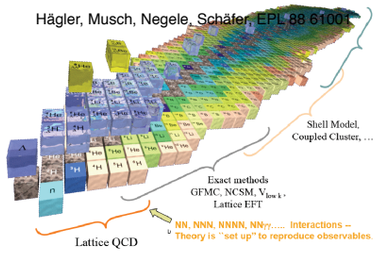
- What observable states does QCD allow?
  - What is the role of the gluons? Is there exotic matter?
  - Focus of GlueX@JLab experiment



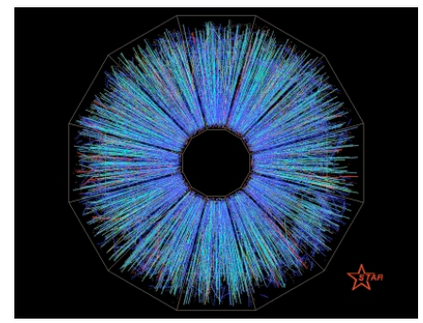
- How does the nucleon's mass & spin arise?
  - How are quarks & gluons distributed in a proton or neutron?
  - Focus of 12 GeV@JLab, RHIC-spin@BNL and & EIC



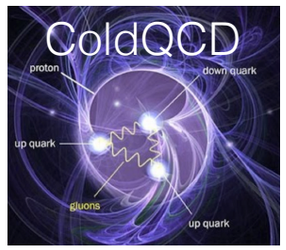
- QCD must predict properties of light nuclei
  - Nuclear reaction properties. Are there new fundamental symmetries?
  - FRIB@Mich. State. will investigate nuclear structure and interactions

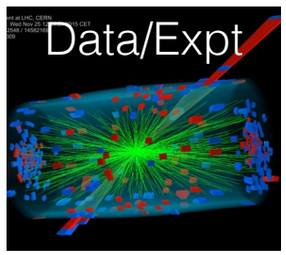


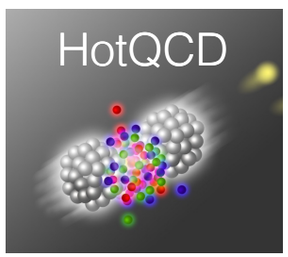
- How does QCD behave under extreme temperatures & pressures such as in supernovae or shortly after Big-Bang?
  - Studied in RHIC@BNL

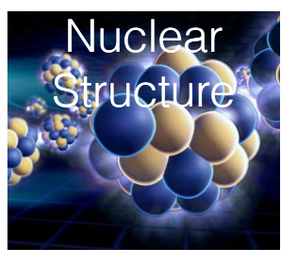


Two tracks to Exascale - Software+Computing









High Energy Physics (HEP)
June 10 – 13, 2015

Basic Energy Sciences (BES)
November 3 – 5, 2015

Fusion Energy Sciences (FES)
January 27 – 29, 2016

Biological and Environmental Research (BER)
March 29 – 31, 2016

Nuclear Physics (NP)
June 15–17, 2016

Advanced Scientific Computing Research (ASCR)
September 27 – 29, 2016

Office of Science Computing and Data Requirements in the Exascale Age

Sponsored by the U.S. Department of Energy,

Exascale Requirements Review for Nuclear Physics

Sponsored by the Department of Energy, Office of Science, Advanced Scientific Computing Research and Nuclear Physics

Hilton Washington DC Nor
620 Perry Parkway
Gaithersburg, MD 20877
June 15-17, 2016

NP Computing and Data Requirements in t

The DOE Office of Science Exascale Requi
key computational domain scientists, and D
requirements for an exascale ecosystem th
workflows, HPC services, and the full-scale
forefront scientific research in Nuclear Phys
June 15-17, 2016, in Gaithersburg, MD. Re

HIGH ENERGY PHYSICS

EXASCALE REQUIREMENTS REVIEW

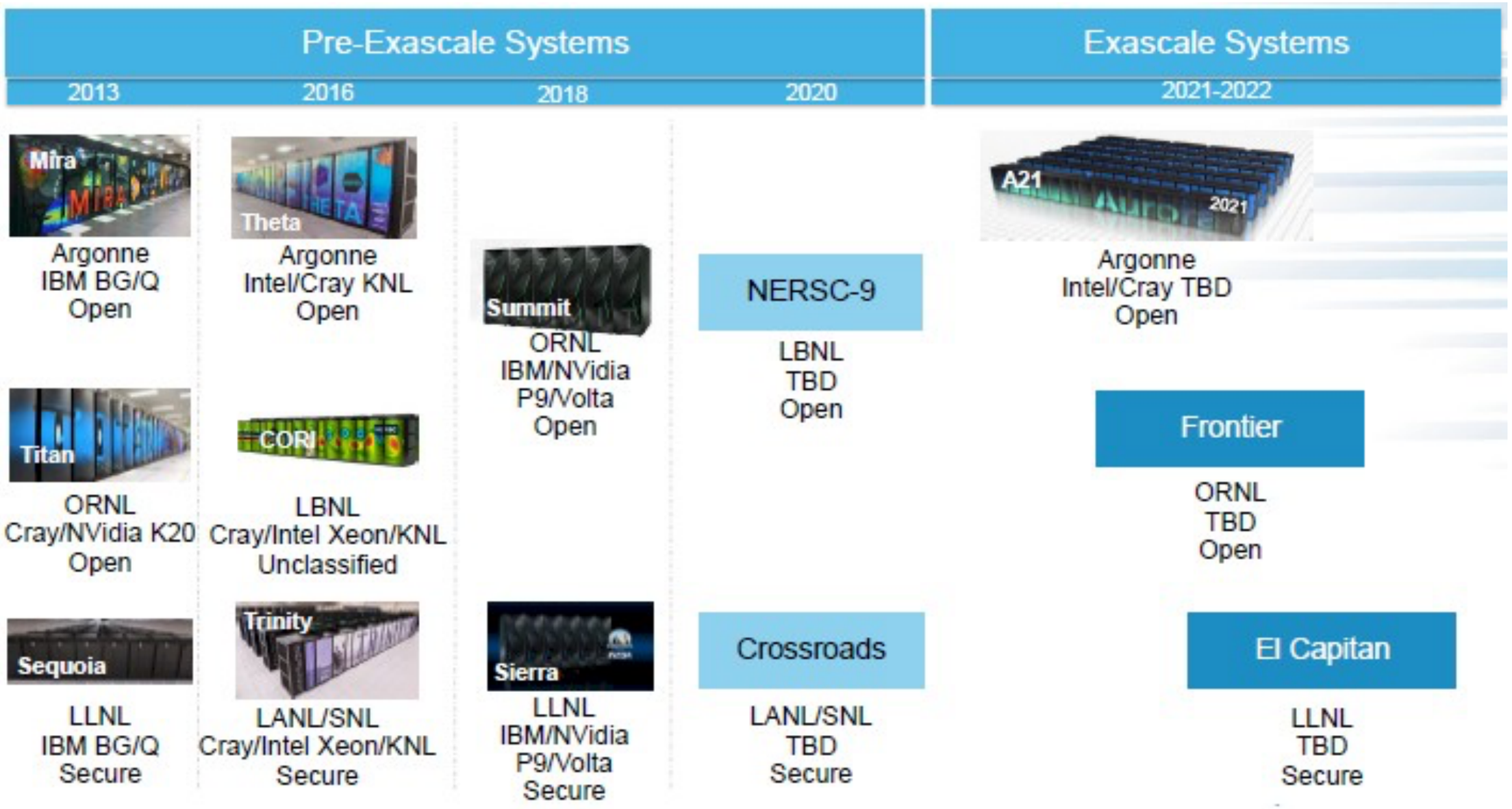
An Office of Science review sponsored jointly by
Advanced Scientific Computing Research and High Energy Physics

ECP
EXASCALE COMPUTING PROJECT

Path to Exascale - system plans

Accelerated deployment to reach exascale

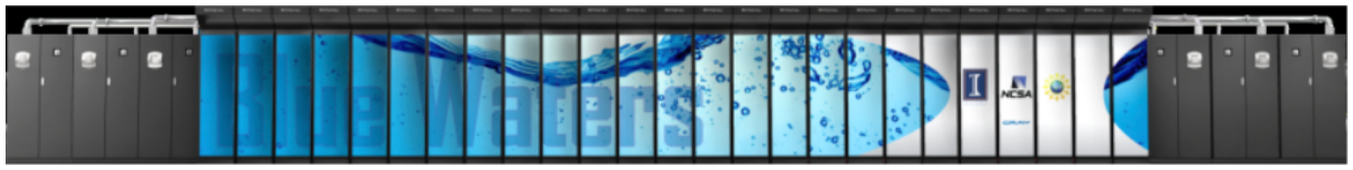
- ➡ coordinated program to deploy pre-exascale systems
- ➡ Exascale systems - ANL[Intel CPU+GPU] (FY21) and ORNL[AMD CPU+GPU] (2023)
- ➡ technology not previously deployed at large scale

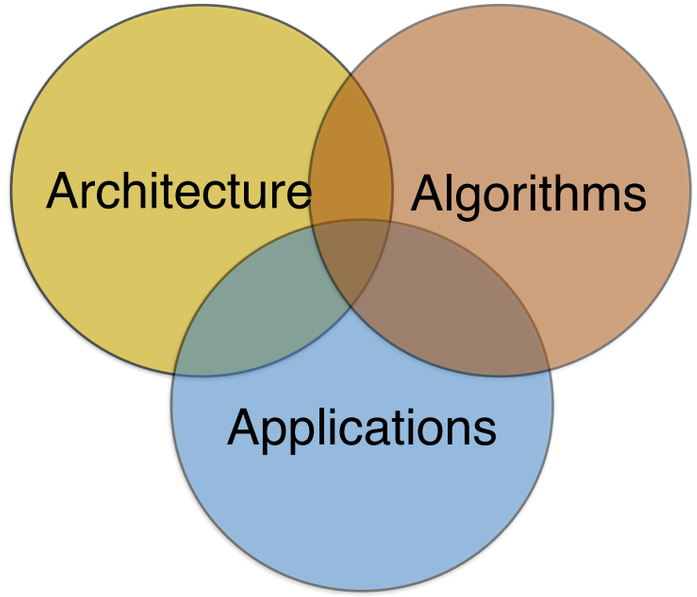


LQCD software development in US

US Lattice QCD coordinated effort involving JLab, BNL & FNAL : ~150 scientists

Software efforts: efficiently utilize national resources leveraged with local/commodity resources





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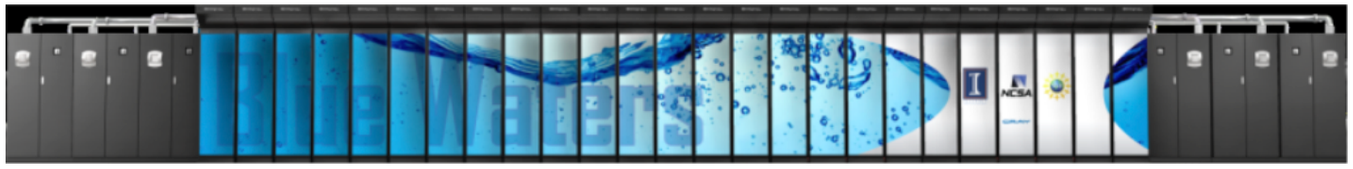
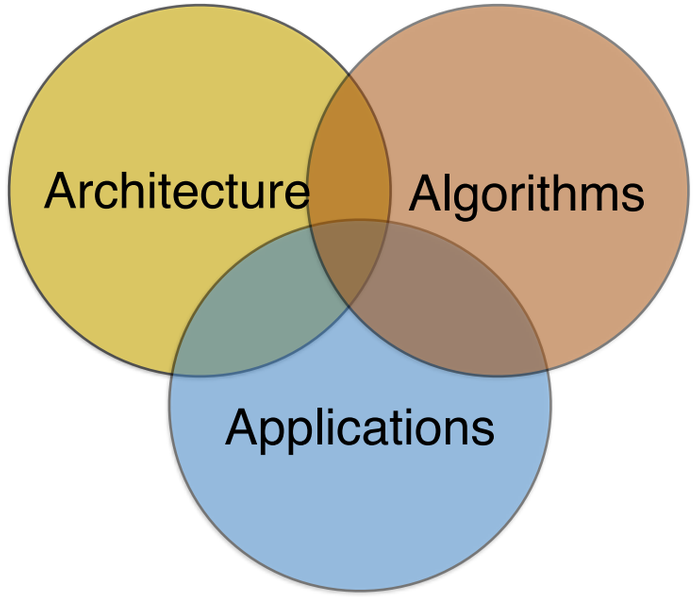




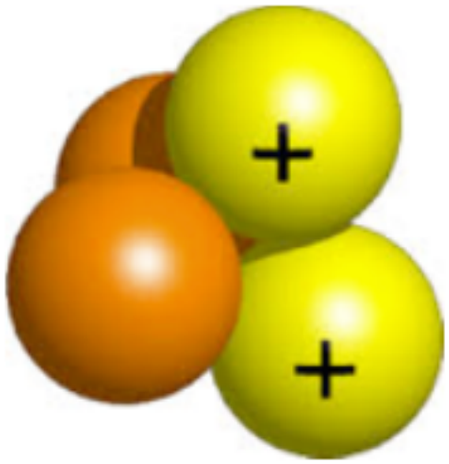
DOE Office of Science - software development grants:

Partners: ASCR: Advanced Scientific Computing Research | HEP: High Energy Physics | NP: Nuclear Physics

2001 - 2012: ASCR/HEP/NP: Scientific Discovery through Advance Computing: 1 & 2
2013 - 2017: HEP + ASCR SciDAC-3
2013 - 2017: NP + ASCR SciDAC-3
2016 - 2020: Exascale Computing Project (ECP)
2017 - 2022: NP + ASCR SciDAC-4

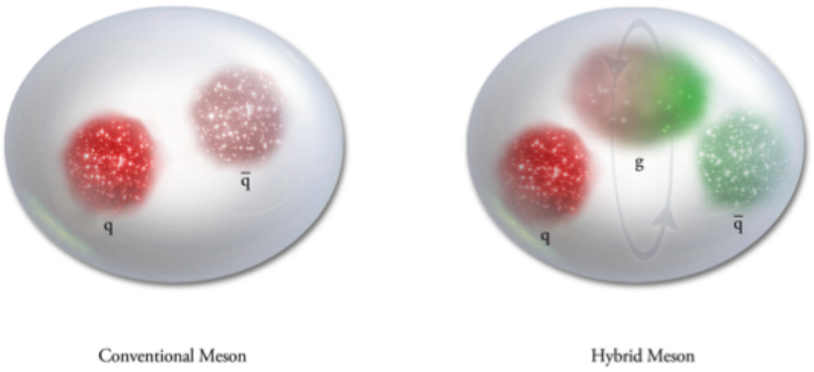
Exascale physics challenge problems

In NP: Compute from first principles the properties and interactions of nucleons and light nuclei with physical quark masses and achieve the multi-physics goal of incorporating both QCD and electromagnetism.



We are now at the cusp of being able to calculate the properties of light nuclei entirely from first principles. Exascale computing will take us all the way there.

Other critical NP problems:
- First principles calculations determining the existence of exotic states of matter – active search in new GlueX experiment at JLab



Conventional Meson Hybrid Meson

Progress - hardware + theory/algorithms

- Hardware
  - LQCD traditionally gets ~15% of all leadership systems over last 30 years.
  - For Exascale, this can be 15% of $1.1B → $150M in equivalent hardware
  - Use local compute resources to leverage (do the small/numerous contraction jobs)
  - Seeing large scale resources for next 7 to 10 years

- Algorithms
  - New/novel algorithmic developments centered on supporting hadronic+nuclear physics
  - Now tractable: multi-meson, nucleon+meson, 2*nucleon, 3*nucleon & matrix elements

- Theory
  - Euclidean space near light-cone formalisms & results (e.g., X.Ji, J. Qiu, A.Radyushkin)
  - LQCD calculations are in finite-volume - this is an important/useful knob
  - LQCD can determine scattering amplitudes - results for mesons, and multi-hadrons ongoing
  - Good prognosis for multi-hadronic matrix elements (see R. Briceno's talk)

E.g., 2+$\mathcal{J}$→2 transition amplitudes