Science: 20 mins: Martin Savage
Hardware: 15 mins: Chip Watson
Code, Algorithms, Production: 35 mins: Robert Edwards

Science from Lattice QCD
Resources at NERSC

Martin J. Savage, Robert Edwards and Chip Watson
May 2011, Washington D.C.

Thursday, May 26, 2011
The Structure and Interactions of Matter from Quantum Chromodynamics

Small number of input parameters responsible for all of strongly interacting matter
Exa-Scale Computational Resources

• **Predictive Capability for Nuclear Physics:** Calculations with quantifiable uncertainties of processes occurring in nuclei, and in dense and hot matter where experiments are not possible.

Exa-scale Computing is required to accomplish the objectives of the Nuclear Physics Research Program
Lattice QCD is initiating a Partial Unification of Nuclear Physics

Cold QCD and Nuclear Forces

Nuclear Structure and Reactions

(Lattice) QCD

Many-Body Methods
EFT, GFMC, NCSM, SRG
Lattice QCD

Monte-Carlo Evaluation of QCD Path Integral

Lattice Spacing: $a \ll 1/\Lambda\chi$
Lattice Volume: $m_{\pi} L \gg 2\pi$

Effective Field Theory gives form of extrapolation $a = 0$ and $L = \infty$

$$\langle \hat{\theta} \rangle \sim \int DU_\mu \hat{\theta}[U_\mu] \det[\kappa[U_\mu]] e^{-S_{YM}}$$

$$\rightarrow \frac{1}{N} \sum_{\text{gluon cfgs}} \hat{\theta}[U_\mu]$$

Thursday, May 26, 2011
The Structure of Hadrons: Cold Lattice QCD

(Derek Leinweber, U. of Adelaide)

Thursday, May 26, 2011
Excited Baryon Spectrum

\[ m_\pi \sim 520 \text{ MeV} \]

NSAC Milestone 2012 HP7: Measure the electromagnetic excitations of the low-lying baryon states and their transition form factors over a range \( Q^2 = 0.1-7 \text{ GeV}^2 \) and measure the electro- and photo-production of final states with one and two pseudoscalar mesons.

The first results on the search for exotic mesons using photon beams will be completed.

Lattice QCD will predict the exotic spectrum before or during the GlueX experiment (with sufficient compute resources).

NSAC Milestone 2018 HP15: The first results on the search for exotic mesons using photon beams will be completed.
NSAC Milestone 2014 HP9: Perform lattice calculations in full QCD of nucleon form factors, low moments of nucleon structure functions and low moments of generalized parton distributions including flavor and spin dependence.
Nuclear Forces and Multi-Hadron Systems

(Derek Leinweber, U. of Adelaide)
Hadronic Interactions

NN-interaction verification

NNN

NNNN

YNN
Lattice QCD and the Simplest Hadronic Interactions

\[ \pi^+ \pi^+ \ (I=2) \]

\[ K^+ K^+ \ (I=1) \]

\[ \pi^+ K^- \ (I=3/2) \]

\[ m_{\pi} g_{\pi \pi} \]

\[ m_{K} g_{K K} \]

\[ \mu_{\pi K} / \sqrt{f_K f_{\pi}} \]

Thursday, May 26, 2011
NSAC Milestone 2014 HP10: Carry out ab initio microscopic studies of the structure and dynamics of light nuclei based on two-nucleon and many-nucleon forces and lattice QCD calculations of hadron interaction mechanisms relevant to the origins of the nucleon-nucleon interaction.
Computational Requirements

The Spectrum and Structure of hadrons

From QCD to Nuclei

- NNN interaction from LQCD
- Alpha particle

- Deuteron axial-charge

- Precision meson-meson interactions

- Baryon-baryon interactions
- Baryon-meson interactions

Sustained Petaflop-Years

0.01 0.1 1 10 100 1000

Sustained Petaflop-Years

0.01 0.1 1 10 100 1000
Nuclear Physics at the Physical Pion Mass

- QCD symmetries

Nuclear Physics is Fine-Tuned
- QCD input parameters
- Our universe is special?

Chiral Behavior
Presentations by
Chip Watson and Robert Edwards
Field has evolved forward rapidly during 2006-2011

More than $10^9$ core-hours per year (average) during 2011-2014 to accomplish relevant near-term NSAC milestones

- physical pion mass (elimination of a major systematic)
- structure of matter
- nuclear forces and the interactions of hadrons
- all codes, algorithms, formalism in place for peta-scale resources

Code evolution to exa-scale

GPU hardware and software deployed
• 2010 - 2011: $\sim 16 \times 10^6$ core-hrs charged and $70 \times 10^6$ core-hrs USED

• $x \: 50: \: 3.5 \times 10^9$ core-hrs

• Transformational for NP: $> 5$ Pflops sustained $\sim 50 \times 10^9$ core-hrs

NERSC Nuclear Physics 2010-2011

x 50

5 Pflop-yrs

Exascale in 2018?

Nuclear Physics “opens up” to Lattice QCD around the Peta-Scale
END