# Computational Nuclear Physics Meeting

*July 14-15*
*SURA, Washington DC*


***David Richards***

***Jefferson Laboratory***


**Organizers: A. Burrows, J. Carlson, R. Edwards, W. Haxton, W. Hix, F. Karsch, W. Nazarewicz, P. Petreczky, D. Richards, M.J. Savage**
**Writing committee: above + W. Detmold and R. Furnstahl**

http://www.jlab.org/conferences/cnp2014/
http://www.jlab.org/conferences/cnp2014/compnuc2014.pdf

***Fundamental Symmetries Town Meeting, Chicago, Sept. 28-29, 2014***


Thanks: the above, + R. Gupta, S. Syritsyn, A. Walker-Loud

# Goals

*"To review the objectives and status of High Performance Computing in Nuclear physics, and to determine the human, software and hardware resources required to successfully accomplish the mission of the Nuclear Physics Program."*

**Previous reports:**

2009 : Exascale meeting – report,
http://science.energy.gov/~/media/ascr/pdf/program-documents/docs/Np_report.pdf

2012 : CNP meeting in D.C. – whitepaper,
http://wwwold.jlab.org/conferences/cnp2012/

2013 : National Academy Report, "Nuclear Physics: Exploring the Heart of Matter"
http://www.nap.edu/catalog.php?record_id=13438
⇒ computation is the 3rd pillar of nuclear physics research

2013: Tribble Committee Report on implementing the 2007 Long Range Plan

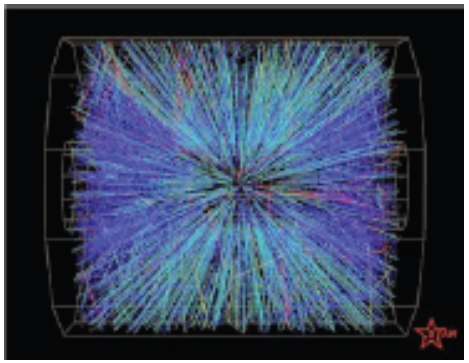
2013: Whitepapers of USQCD:
http://www.usqcd.org/documents/13nuclear.pdf
http://www.usqcd.org/documents/13flavor.pdf
} ***Focus for this Town Meeting***

**Opportunities for fundamental symmetries distilled to position paper to this session**

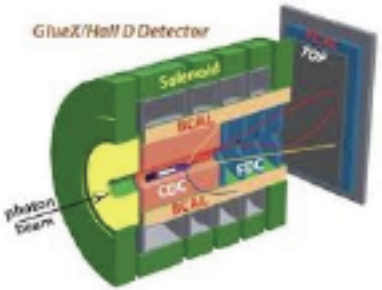
**"Fundamental Symmetries, Precision Probes of the Standard Model and Lattice QCD",**
***A. Walker-Loud, W. Haxton et al***

# Physics Thrusts

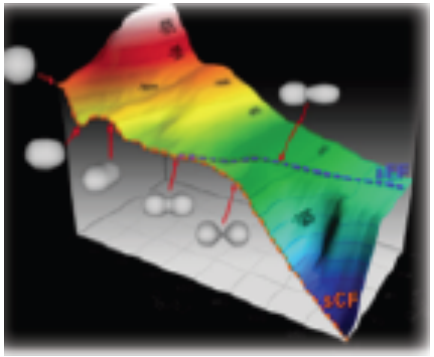
Hot QCD



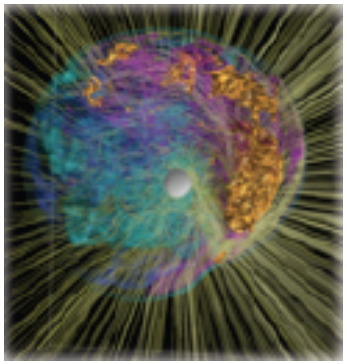
Cold QCD: Hadron and Nuclei




Nuclear Structure and Reactions



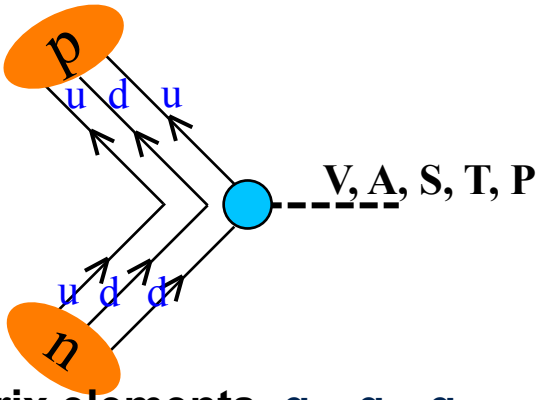
Nuclear Astrophysics



Nearly all these areas impact studies of Fundamental Symmetries

# Nucleon Charges

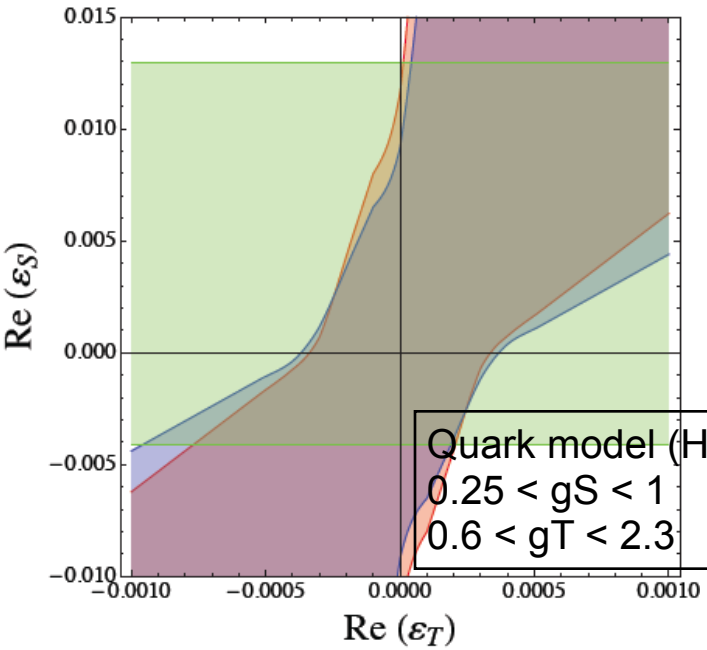
e.g. novel interactions probed in ultra-cold neutron decay



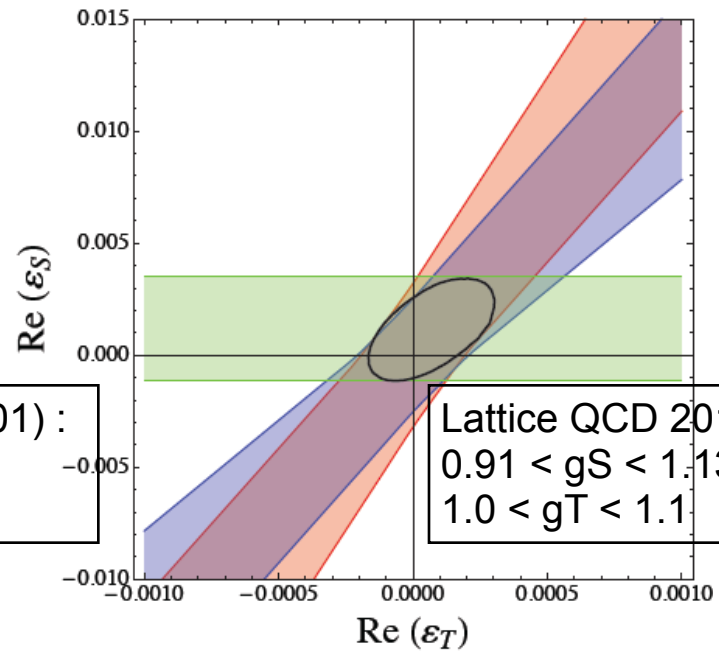

$$H_{eff} \supset G_F\left[\varepsilon_S\, \bar{u}d \times \bar{e}(1-\gamma_5)\nu_e + \varepsilon_T\, \bar{u}\sigma_{\mu\nu}d \times \bar{e}\sigma^{\mu\nu}(1-\gamma_5)\nu_e\right]$$

$$g_S = Z_S \langle p|\bar{u}d|n\rangle \quad g_T = Z_T \langle p|\bar{u}\sigma_{\mu\nu}d|n\rangle$$

**Require precise knowledge of QCD nucleon matrix elements, $g_A$, $g_T$, $g_S$**

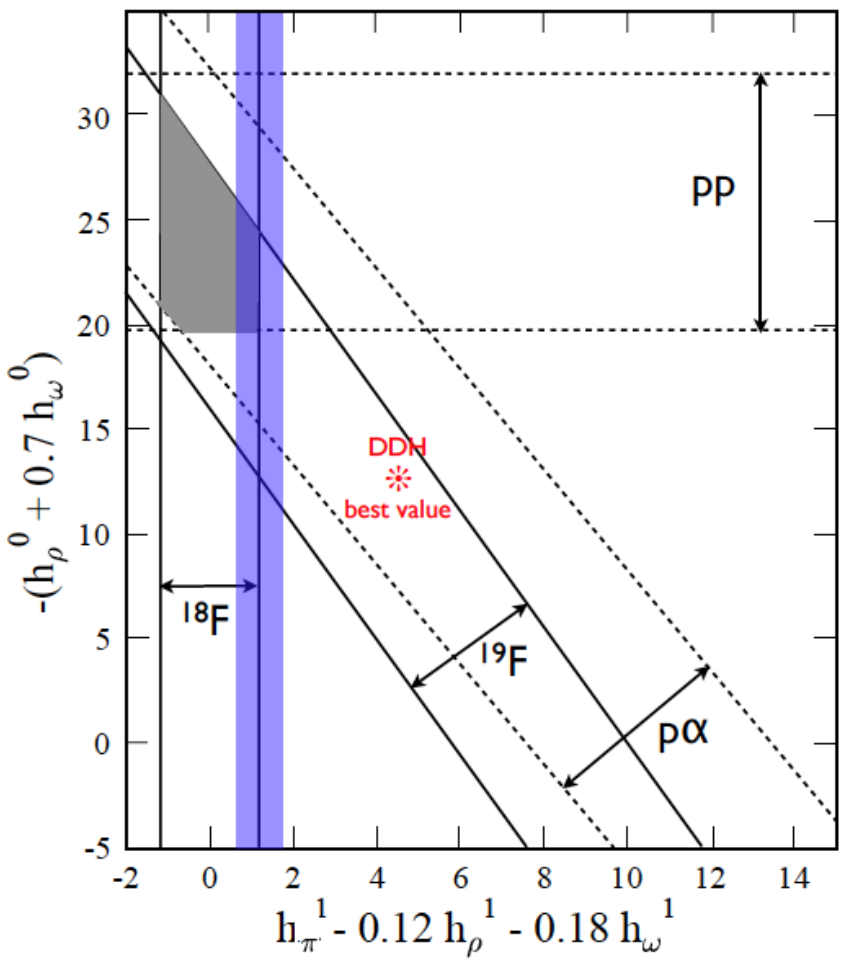



Quark model (Herczeg 2001) :
0.25 < gS < 1
0.6 < gT < 2.3




Lattice QCD 2014 (R. Gupta)
0.91 < gS < 1.13
1.0 < gT < 1.1

# Nuclear Parity Violation

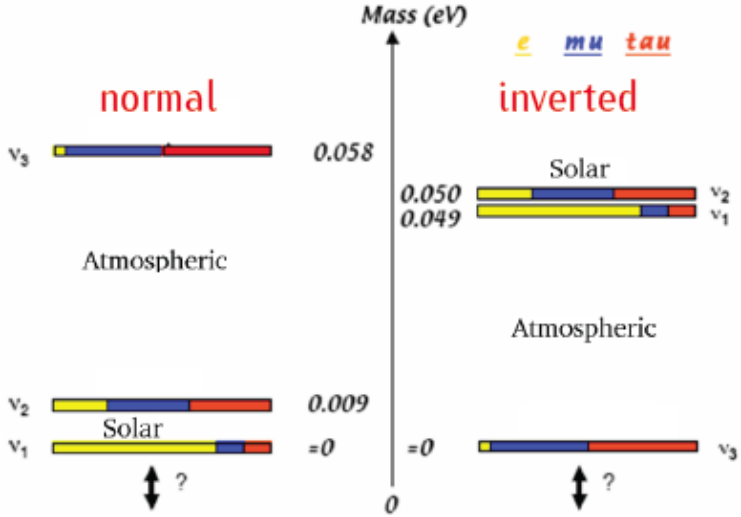


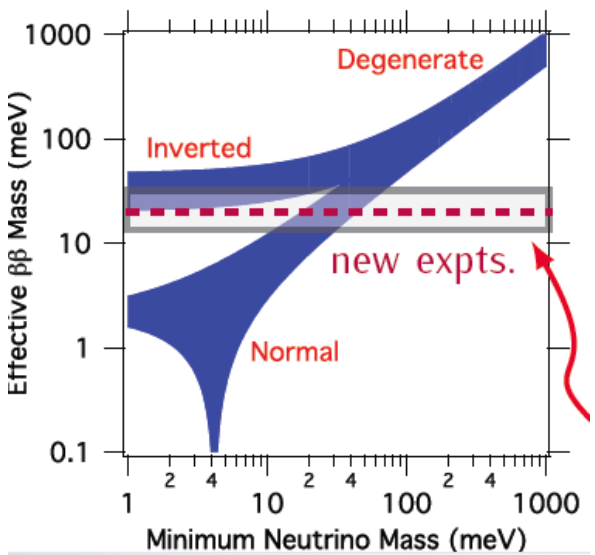

J. Wasem, Phys. Rev. C 85, 022501(R) (2012)

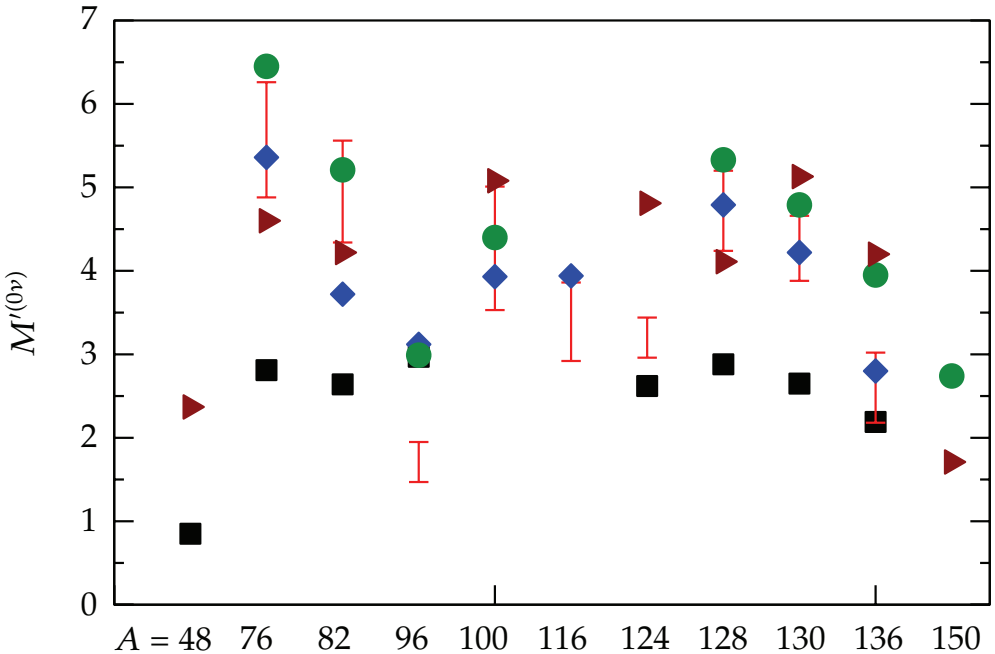
First lattice investigation of nuclear parity violation

$np \to d\gamma$

# Neutrinoless Double-Beta Decay




Shell model

Interacting boson model

Generator coordinate method

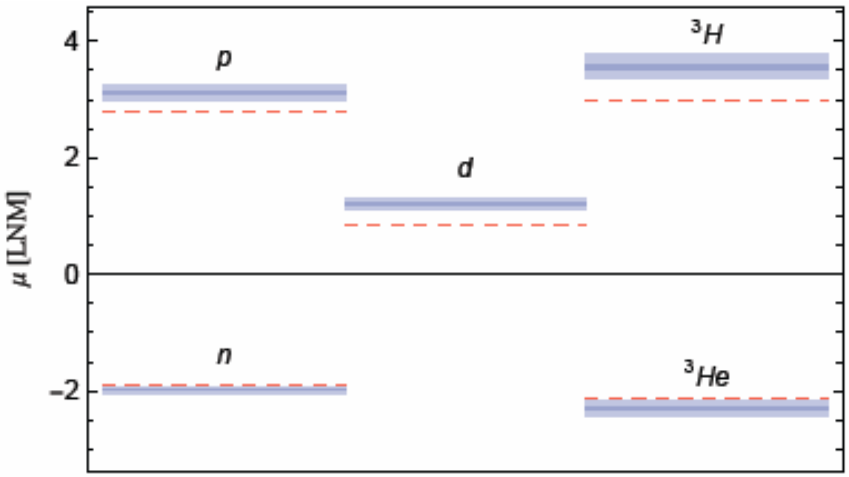
QRPA

Nuclear Uncertainties

Spread representative of the true uncertainty?

# Nuclear Matrix Elements in LQCD

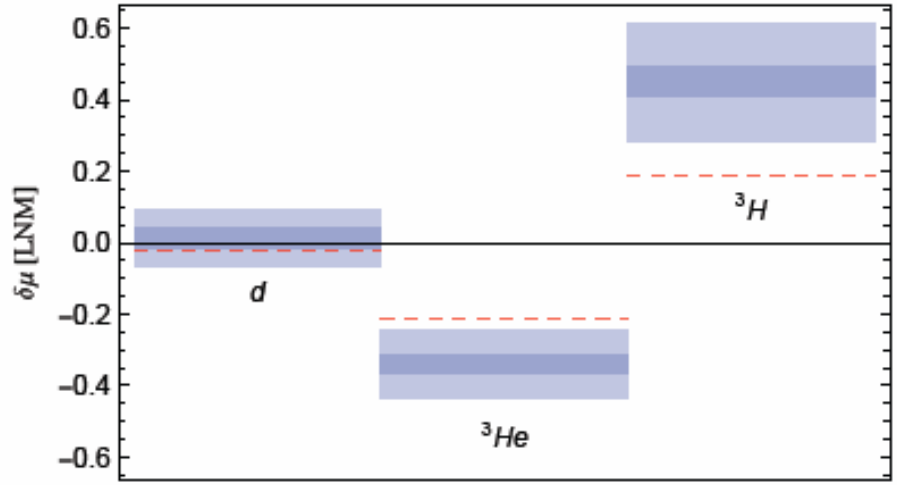
- Demonstrated for lightest nuclei
- Calculation of magnetic moments of lightest nuclei.




Experimentally measured values

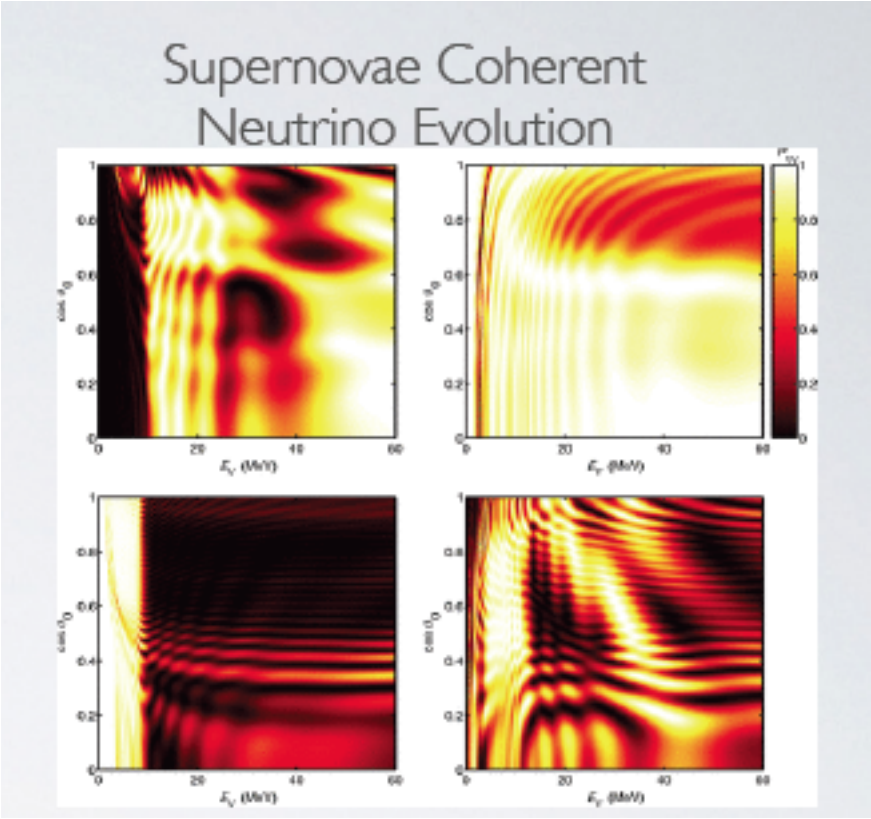
$m_\pi \simeq 800$ MeV

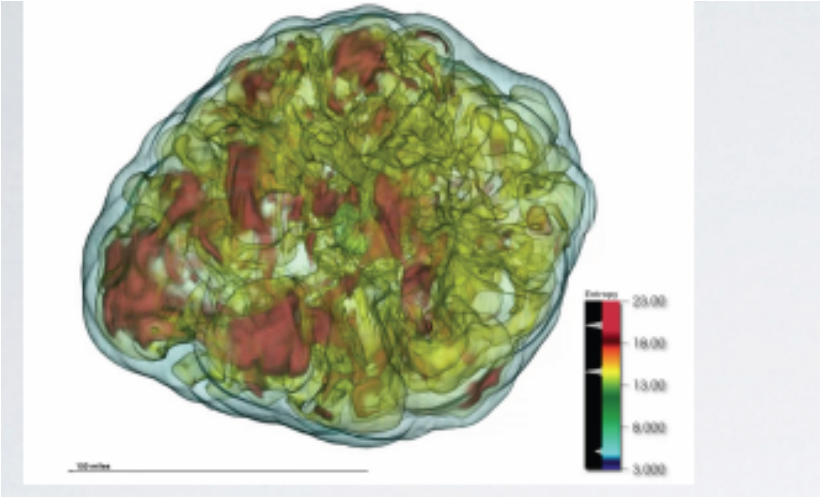
NPLQCD, arXiv:1409.3556




Differences from naive shell model

# Supernovae



**Core-collapse supernovae**: 3D codes with spectral neutrino transport becoming available

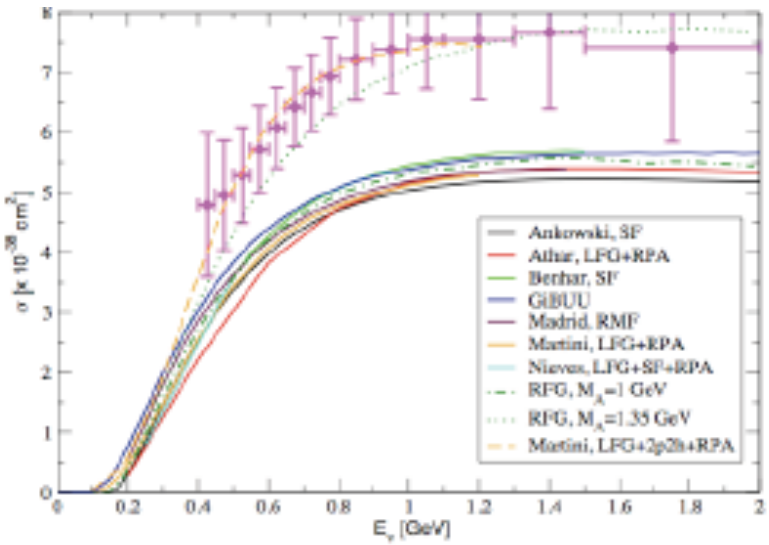
Laboratory for
- neutrino nuclear physics
- neutrino flavor mixing

# Neutrino-Nucleus Scattering

Important across NP and Astrophysics

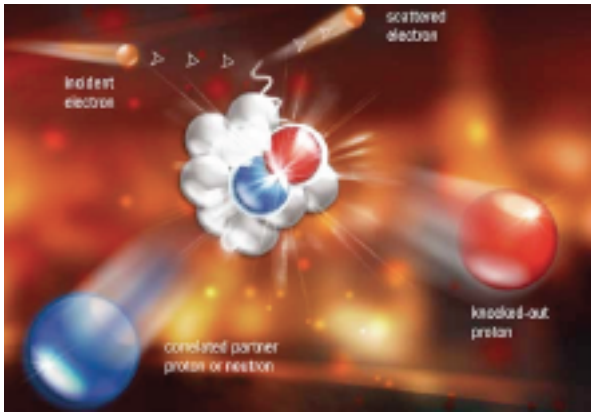
- Supernovae
- Neutron stars
- Terrestrial detectors

***Expt vs. simple theories***




## Future challenges

- Explore the role of correlations and currents in important transitions
- Understand the energy-dependence of neutrino and antineutrino inclusive cross-sections including realistic currents and correlations
- Explore neutrino propagation in dense matter including:
  - superfluidity in neutron star matter and its cooling
  - finite-temperature studies of neutrino spectra as they decouple from the proto-neutron star
  - neutrino processes in neutron-rich nuclei




**Enhancement correlated with np-pair correlations and currents measured in electron scattering**

# Goals for next three years…

**Computational Nuclear Physics across subfields is essential to probe new physics.**

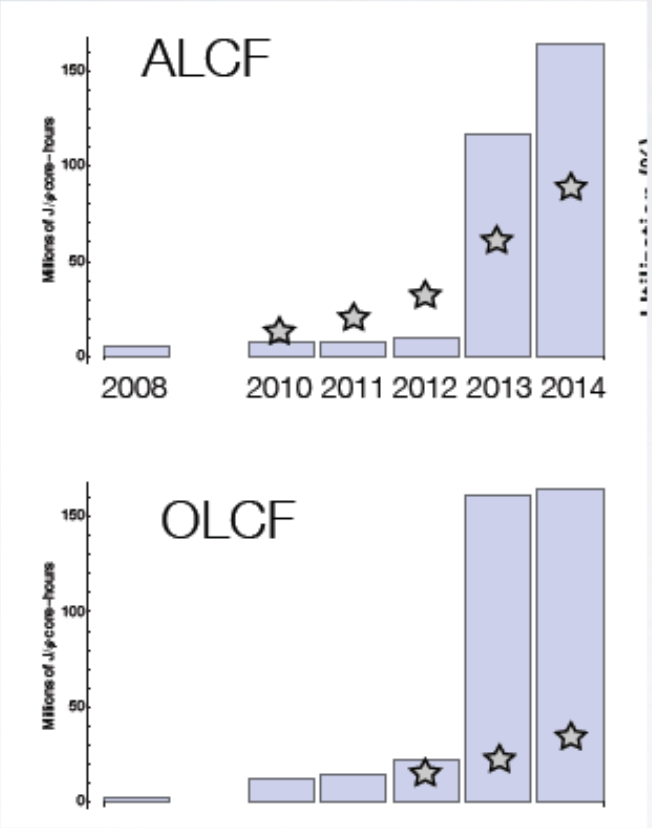
- $g_A$ to 4% LQCD
- $g_S$ and $g_T$ to 10% LQCD
- isoscalar $g_T$ to 20%. LQCD

  Quark EDM for neutron
- Neutron EDM arising from theta term LQCD
- Hadronic parity violation LQCD
- CP-odd NN Interactions LQCD + Structure and Reactions
- Nuclear Matrix elements and nuclear structure calculations LQCD + Structure and Reactions

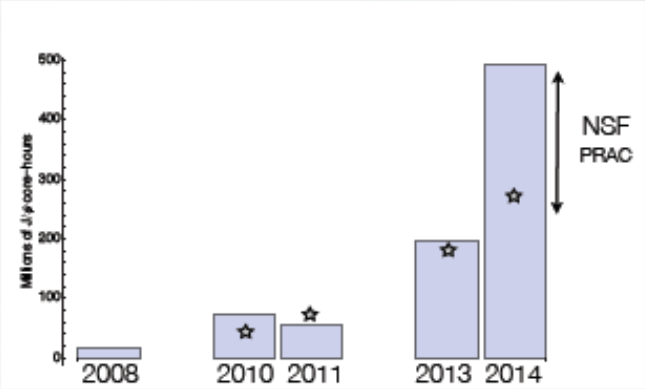
  Design and interpretation of neutrino-less double-beta decay experiments
- Improved models of supernovae

  Effects of neutrinos on nucleosynthesis, and interpretation of neutrinos in underground detectors Nuclear Astrophysics + Structure and Reactions

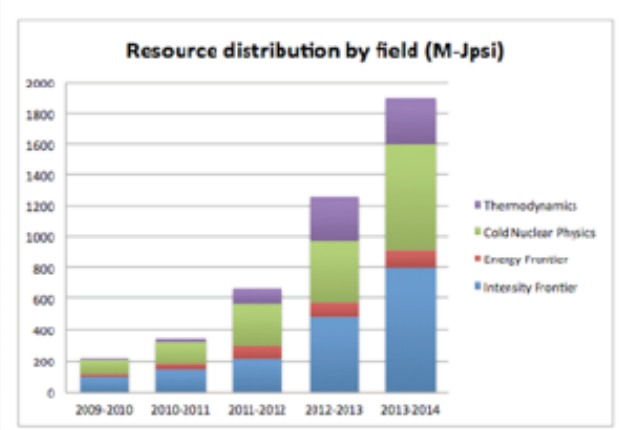
# Computational Resources




NUCLEI




Nuclear Astrophysics




Lattice QCD

**Growing rapidly…**

# Computer Architectures

**Changing rapidly…**

**…next NERSC system Intel Phi**

# HUMAN RESOURCES

SciDAC
Scientific Discovery through Advanced Computing

3 Projects Currently Supported :

*Computing Properties of Hadrons, Nuclei and Nuclear Matter from Quantum Chromodynamics - LQCD*

*Nuclear Computational Low-Energy Initiative* (NUCLEI)

*A Multi-Scale Approach to Nuclear Structure and Reactions: Forming the Computational Bridge between Lattice QCD and Non-relativistic Many-Body Theory* (CalLAT)

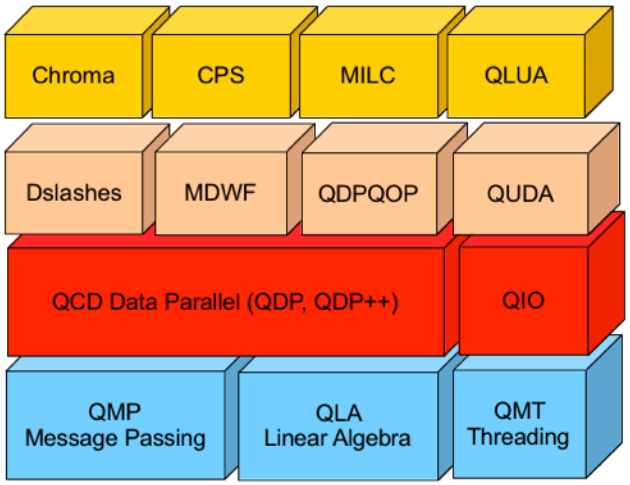
SciDAC support significantly reduced in 2012

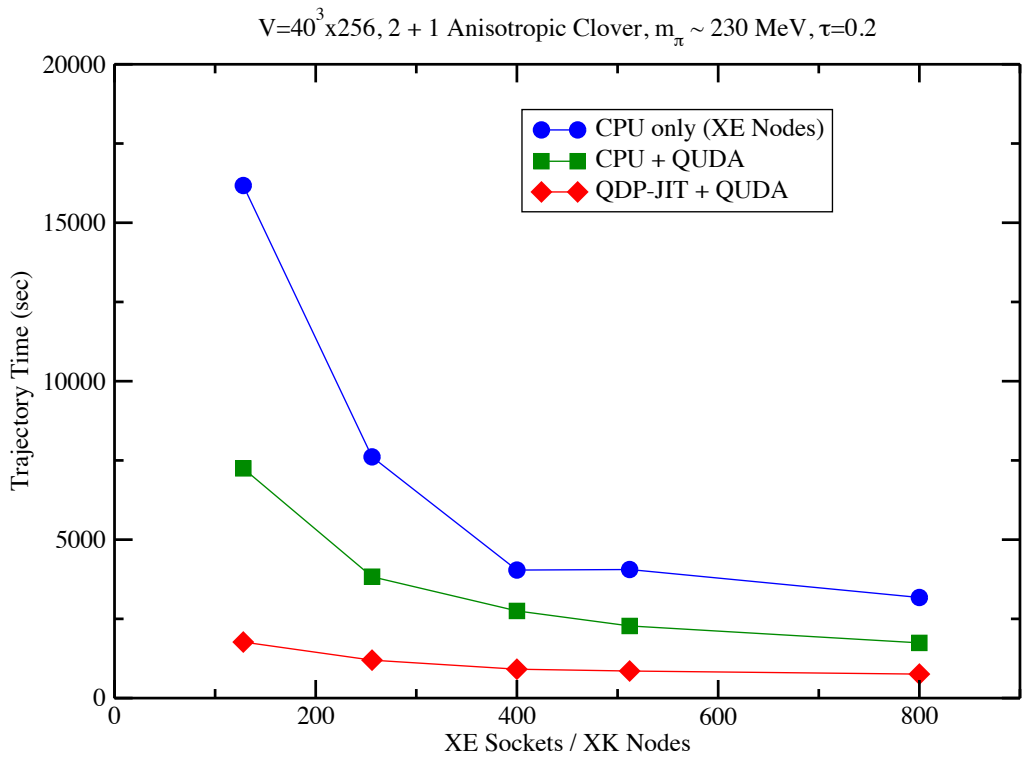
- *Some projects/areas defunded, e.g. astrophysics, and all are under funded*

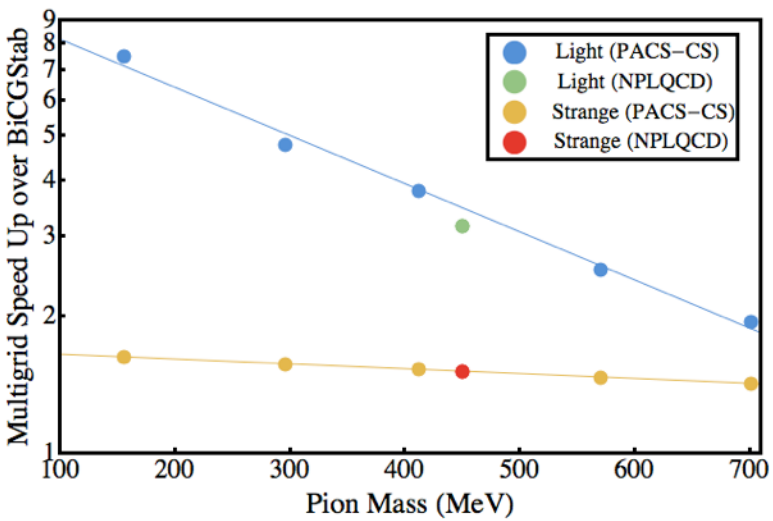
Leadership-class (and external) resources depend upon it (leveraged)

- *dictates code sophistication, readiness and competitiveness*

# Impact of SciDAC: LQCD




**Time to generate gauge fields**

# Faculty Positions…

| Person | Field | Institution |
|---|---|---|
| 2014 | | |
| Hasan Metin Aktulga | (CS) | Michigan State U |
| Heiko Hergert | (NS/R) | Michigan State U, 5 year |
| Nobuo Hinohara | (NS/R) | U of Tsukuba |
| Jason Holt | (NS/R) | TRIUMF |
| Jeremy Holt | (NS/R) | U Washington, 5 year |
| Alessandro Lovato | (NS/R) | Argonne |
| Stefan Meinel | (Cold QCD) | Arizona, RIKEN |
| Ken Nollet | (ASTRO/NS/R) | SDSU (offered) |
| Hiroshi Ohno | (Hot QCD) | U of Tsukuba |
| Bjoern Schenke | (Hot QCD ) | Brookhaven |
| Andrew Steiner | (ASTRO) | U of Tennessee |
| Christopher Thomas | (Cold QCD) | U of Cambridge |
| 2013 | | |
| Silas Beane | (Cold QCD) | U of Washington |
| Michael Forbes | (NS/R) | Wash State U |
| Ming Gong | (Cold QCD) | Institute of High Energy Physics (China) |
| Elena Litvinova | (NS/R) | Western Michigan U |
| Tom Luu | (Cold QCD) | Jülich |
| Hannah Petersen | (Hot QCD) | Frankfurt |
| Andre Walker-Loud | (Cold QCD) | William & Mary/ JLab |
| Frank Winter | (Cold QCD) | JLab |
| 2012 | | |
| William Detmold | (Cold QCD) | MIT |
| Heng Tong Ding | (Hot QCD) | Wuhan U |
| Alex Gezerlis | (NS/R) | Guelph |
| Harvey Meyer | (Cold and Hot QCD) | University of Mainz |
| Junchen Pei | (NS/R) | Pekin U |
| Masha Sosonkina | (NS/R) | Old Dominion University |
| Michael Strickland | (Hot QCD) | Kent State |
| Joseph Wasem | (Cold QCD) | LLNL |

**Computational Nuclear Physics obtain faculty positions…**

# …..Faculty Positions

| Person | Institution | Award | Year |
|---|---|---|---|
| Andre Walker-Loud | William & Mary | DOE Early Career | 2014 |
| Bjorn Schenke | Brookhaven | DOE Early Career | 2014 |
| William Detmold | MIT | DOE Early Career | 2013 |
| Carla Fröhlich | NC State | DOE Early Career | 2013 |
| Gaute Hagen | ORNL | DOE Early Career | 2013 |
| Paul Romatschke | Colorado | DOE Early Career | 2012 |
| Daniel Kasen | UC Berkeley/LBL | DOE Early Career | 2012 |
| Andrei Alexandru | GWU | NSF Career | 2012 |
| Jo Dudek | Old Dominion | DOE Early Career | 2011 |
| Sophia Quaglioni | LLNL | DOE Early Career | 2011 |
| Denes Molnar | Purdue | DOE Early Career | 2010 |
| William Detmold | William & Mary | DOE NP OJI | 2009 |

**… and win awards.**

# Recommendation and Request

***Recommendation:*** Realizing the scientific potential of current and future experiments demands large-scale computations in nuclear theory that exploit the US leadership in high-performance computing. Capitalizing on the pre-exascale systems of 2017 and beyond requires significant new investments in people, advanced software, and complementary capacity computing directed toward nuclear theory.

**Request:** To this end, we ask the Long-Range Plan to endorse the creation of an NSAC subcommittee to to develop a strategic plan for a diverse program of new investments in computational nuclear theory. We expect this program to include:

- *new investments in SciDAC and complementary efforts needed to maximize the impact of the experimental program;*
- *development of a multi-disciplinary workforce in computational nuclear theory;*
- *deployment of the necessary capacity computing to fully exploit the nation's leadership-class computers;*

with support ramping up over five years towards a level of around $10M per annum.

**WE ASK YOUR ENDORSEMENT**