Cold QCD

Meeting on Computational Nuclear Physics

Washington, DC July 2012

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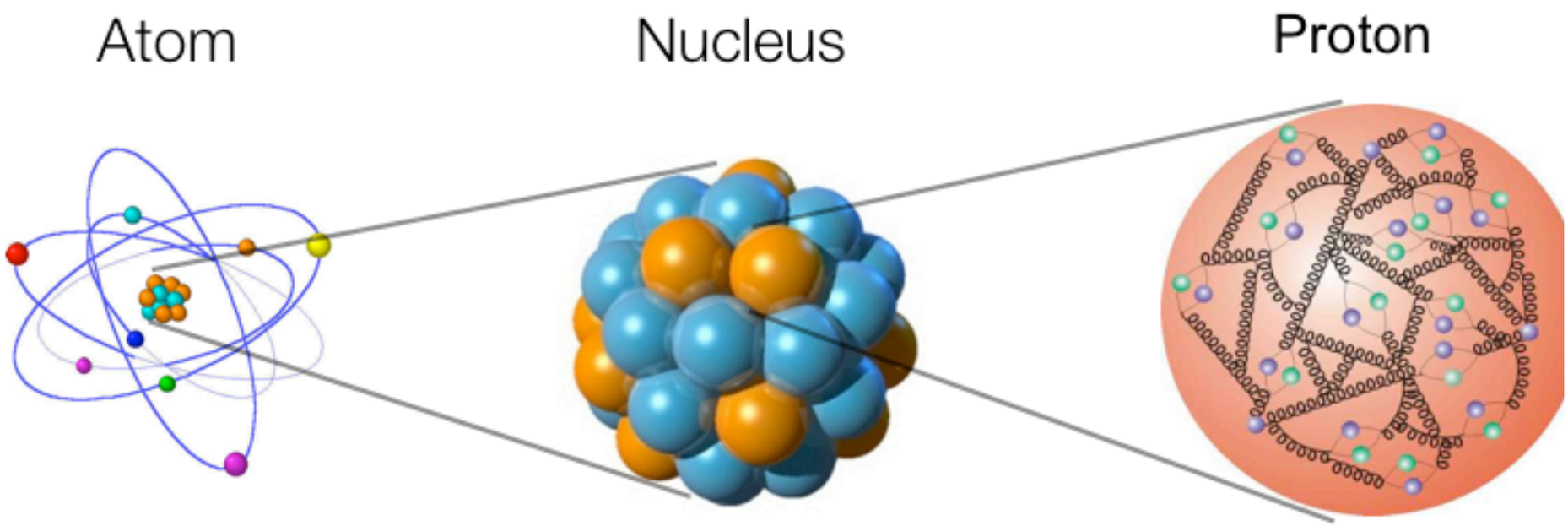
A little perspective



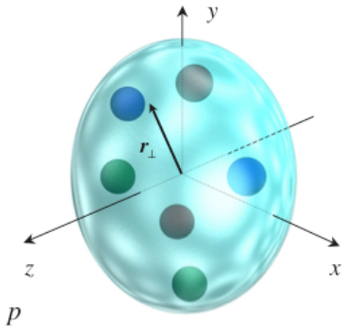
Angstrom Fermi $<$ Fermi

10 meters 10^{-15} meters

ColdQCD

The interactions between quarks and gluons leads to diverse phenomena

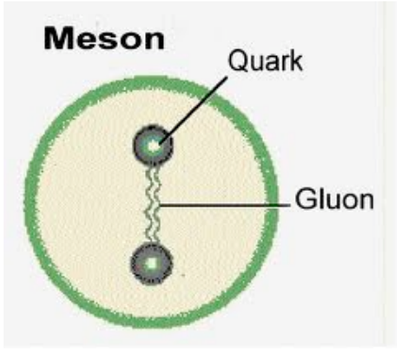
Hadron Structure



How is the spin of a nucleon partitioned?

How exactly do quarks and gluons make a nucleon?

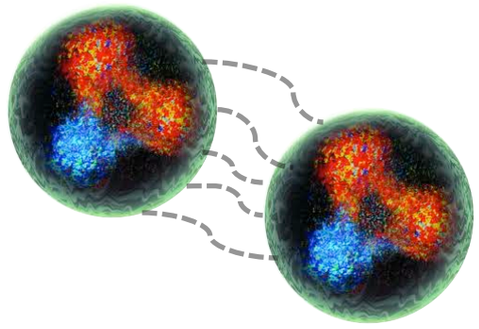
Hadron Spectroscopy



What is the spectrum of QCD?

How does confinement manifest itself?

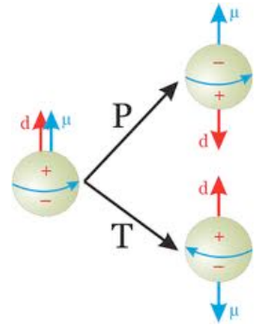
Hadron Interactions



What is the exact lineage of the nuclear force from QCD?

What are consequences of nuclear fine tunings?

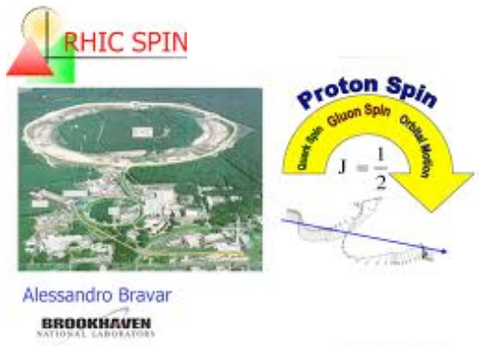
Fundamental Symmetries

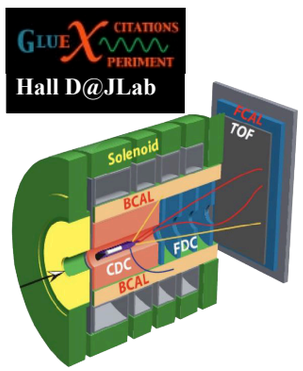


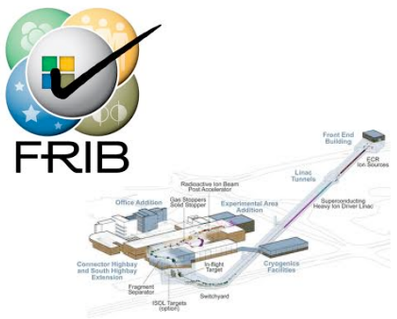
How do symmetry violations manifest themselves?

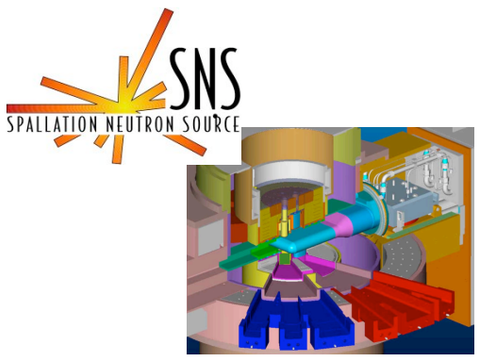
Where are BSM signatures best determined?

These efforts support a host of DOE experimental programs



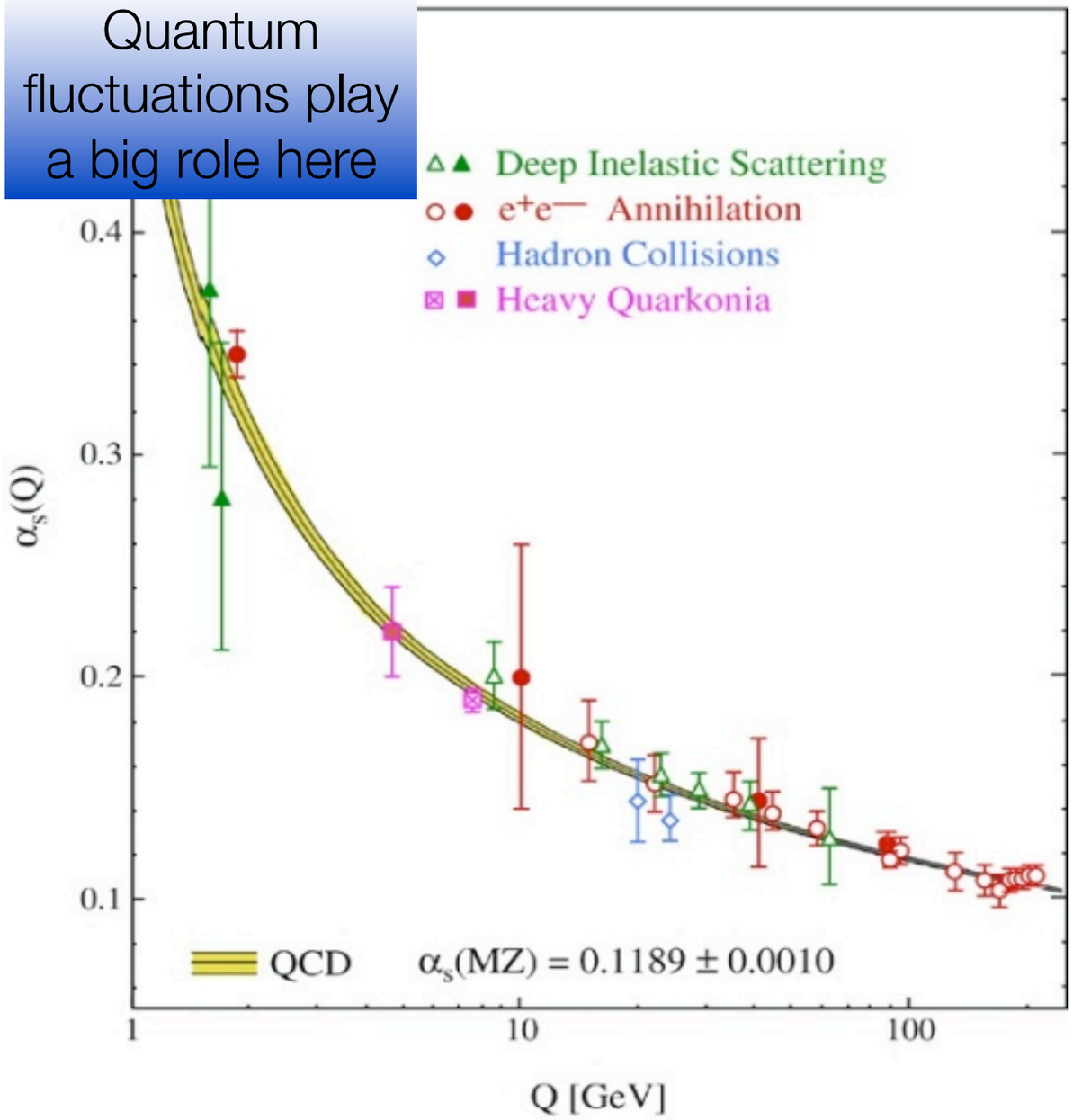


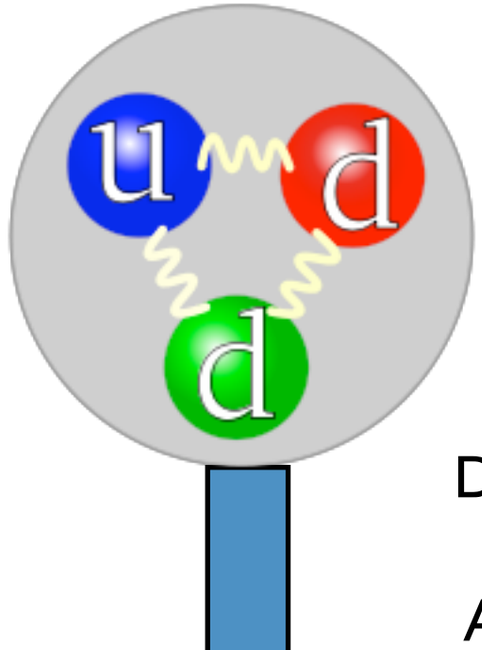




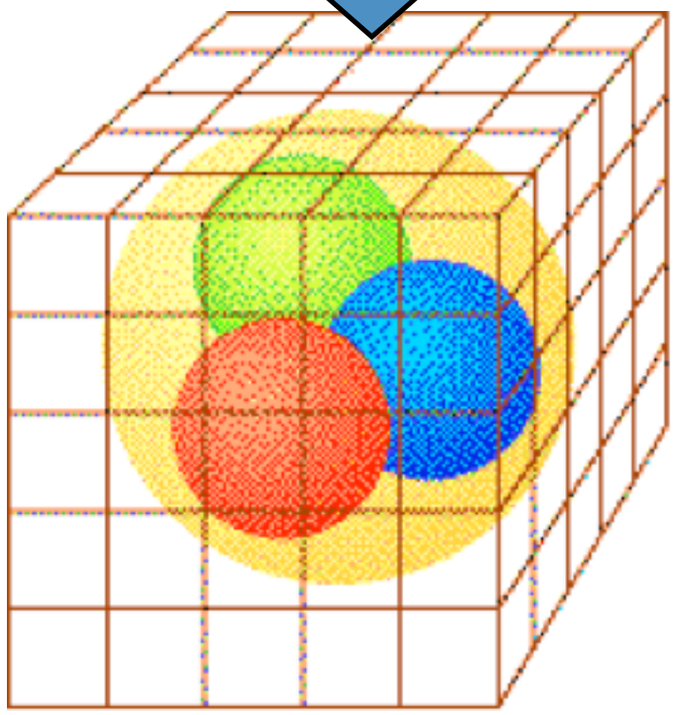
Nuclear Physics: Strongly interacting limit of QCD

Quantum fluctuations play a big role here





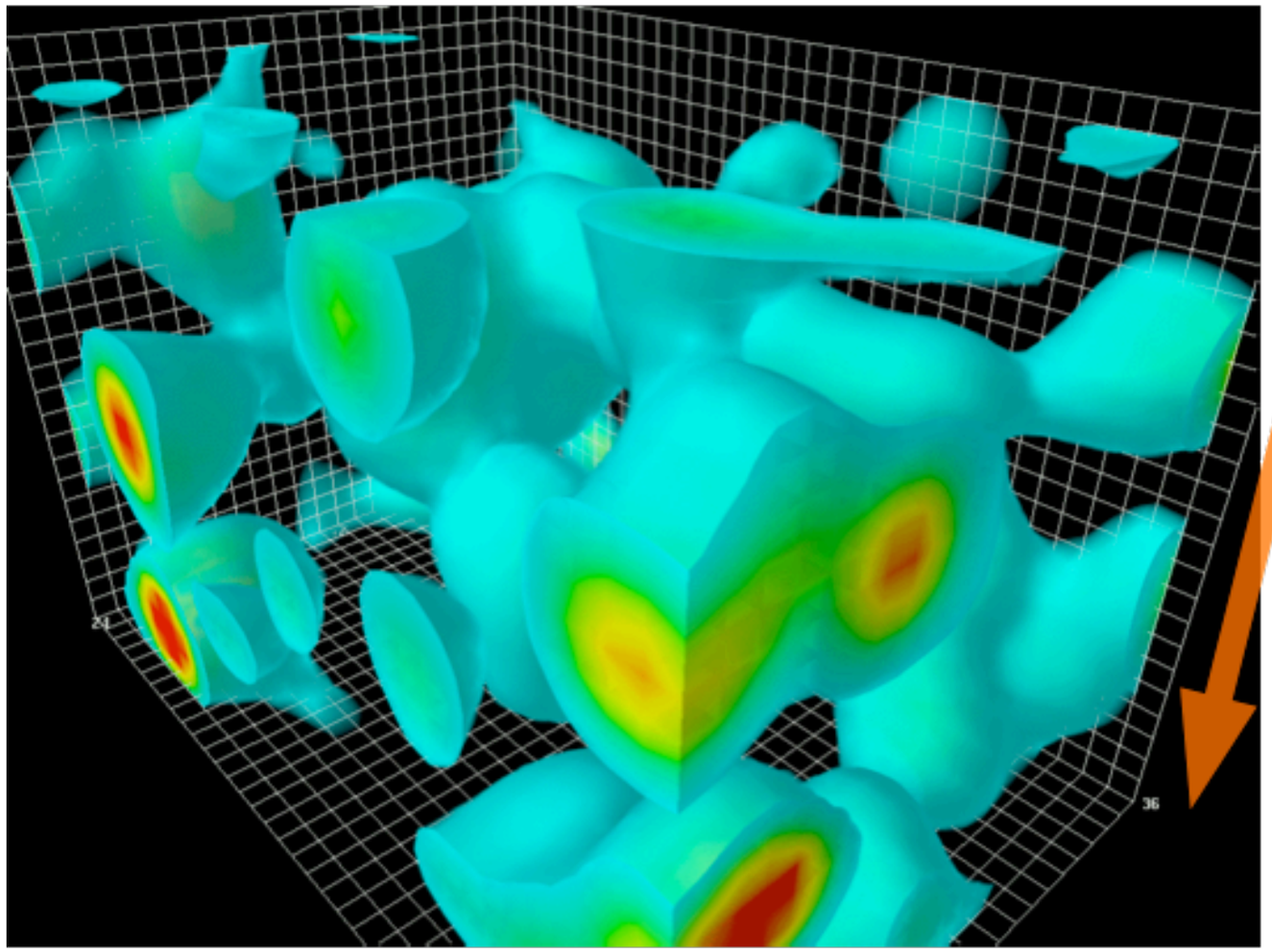
Discretize space-time in a box
Apply stochastic methods



QCD must be tamed numerically in this limit

The QCD 'vacuum' is a very complicated entity

Action Density



(Derek Leinweber, U. of Adelaide)

Quantum Fluctuations of the Gluon Fields

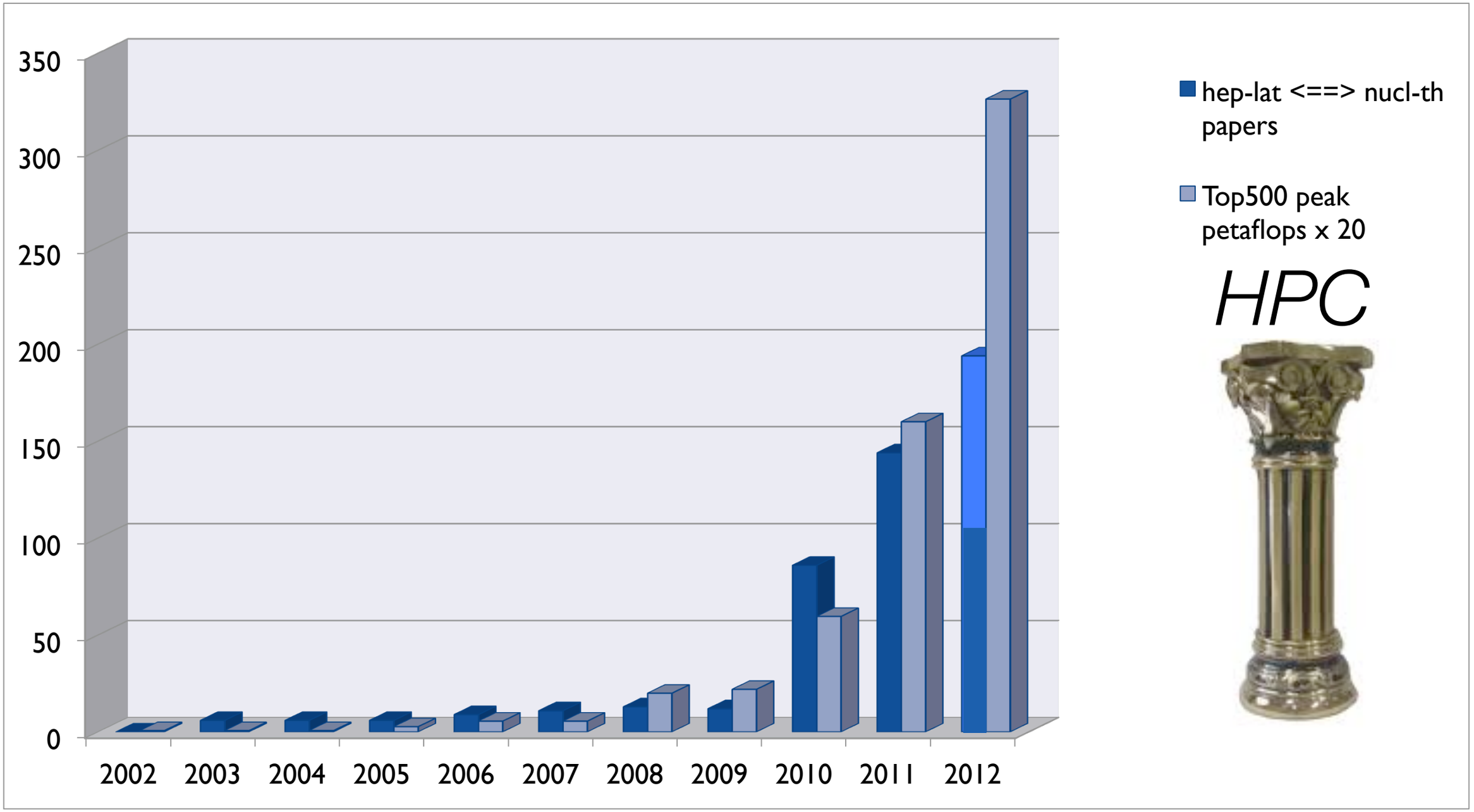
$$2.5 \times 10^{-15} \text{ m}$$

$$\Delta t \sim 10^{-23} \text{ s}$$

$$\Delta E \sim 1\% \text{ of hadron mass}$$

QCD is a dynamical, multi-scale problem that requires large HPC resources

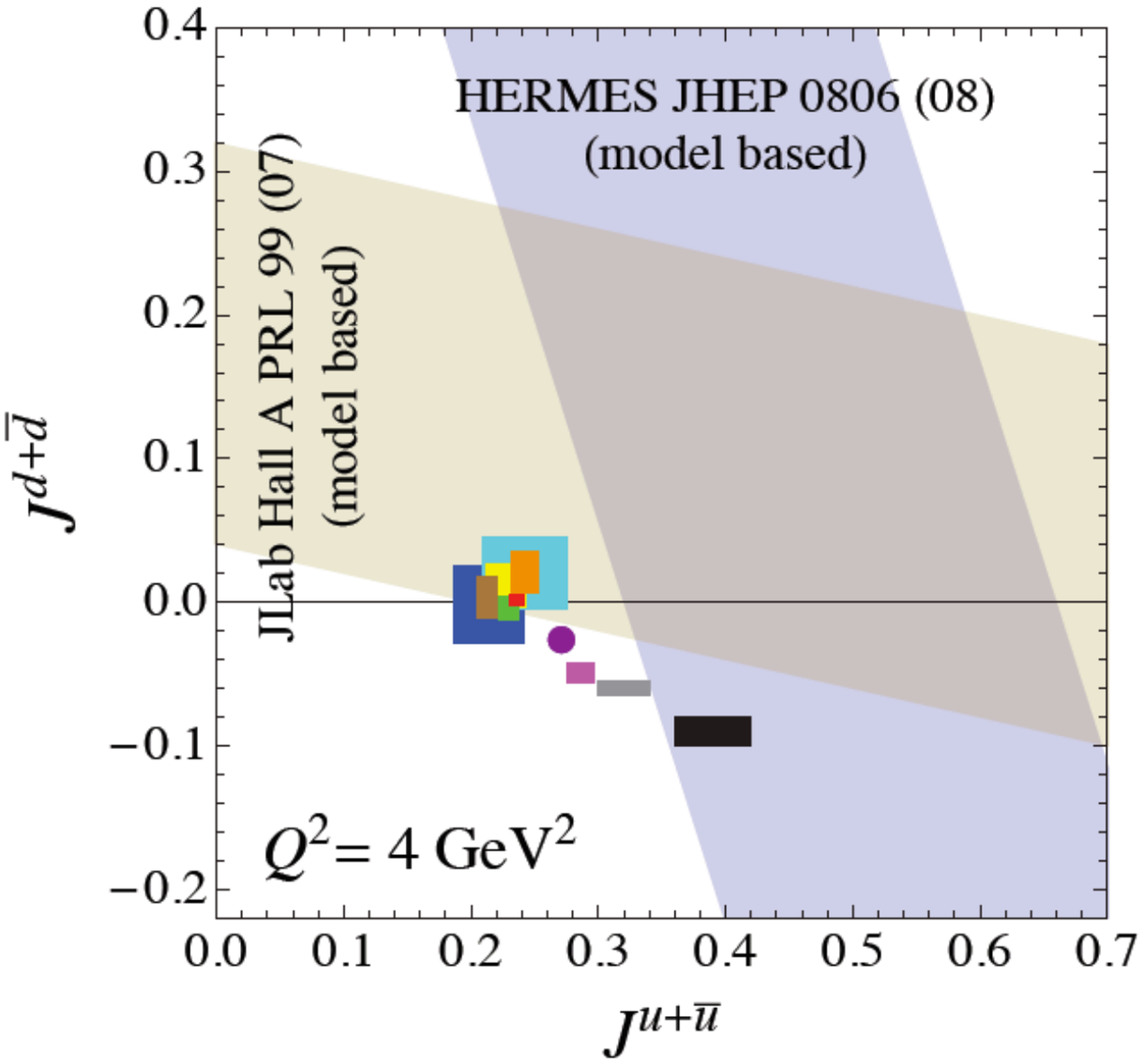
HPC is *Enabling Growth* and *Strengthening Ties* within Nuclear Physics



What does it take to sustain this growth?

We are now understanding the nature of the nucleon spin

Figure courtesy of A. Bacchetta and M. Radici



Goloskokov & Kroll, EPJ C59 (09) 809

Diehl et al., EPJ C39 (05) 1

Guidal et al., PR D72 (05) 054013

Liuti et al., PRD 84 (11) 034007

Bacchetta & Radici, PRL 107 (11) 212001

LHPC–1, PR D77 (08) 094502

LHPC–2, PR D82 (10) 094502

QCDSF, arXiv:0710.1534

Lattice calculations

Wakamatsu, EPJ A44 (10) 297

Thomas, PRL 101 (08) 102003

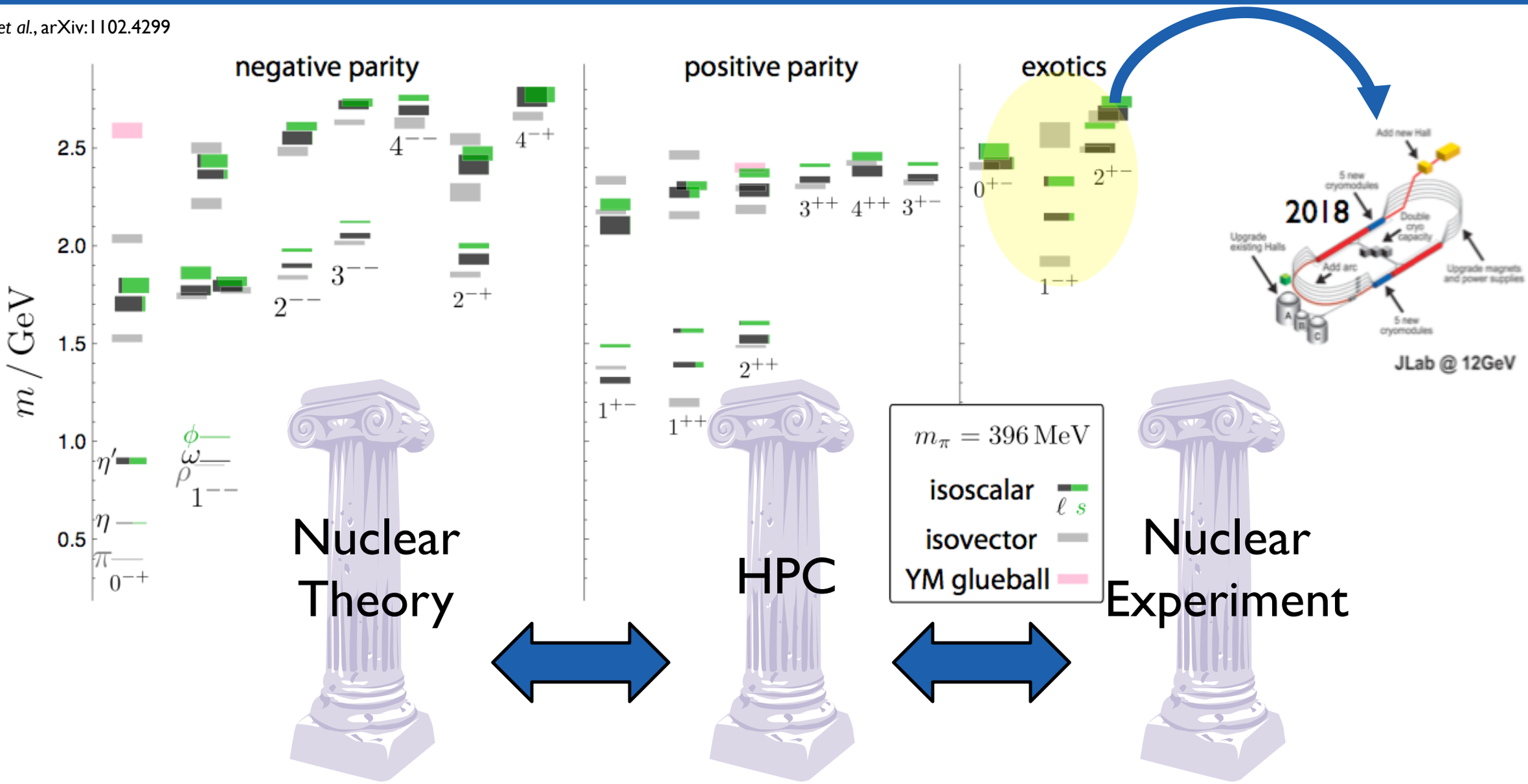
Thomas, INT 2012 workshop

~50% of a nucleon's spin comes from the gluons

HP9 (2014) "*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*"

Calculations of exotic mesons are guiding experimental efforts

J. Dudek *et al.*, arXiv:1102.4299

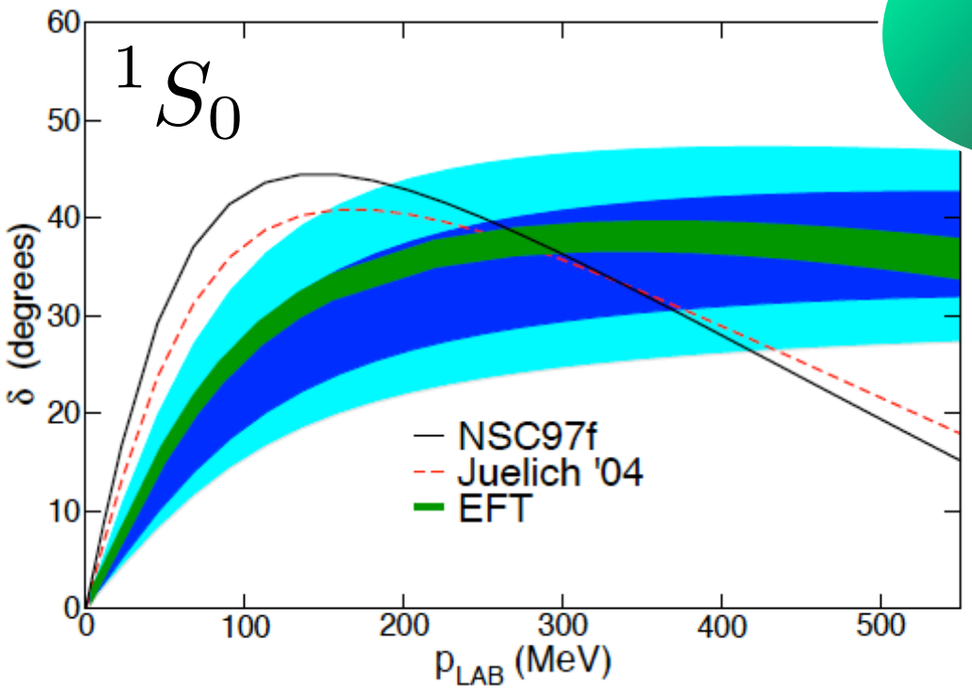


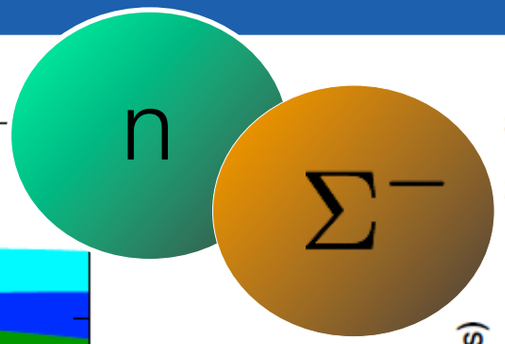
(HP15) *"First results on the search for exotic mesons using photon beams will be completed"*

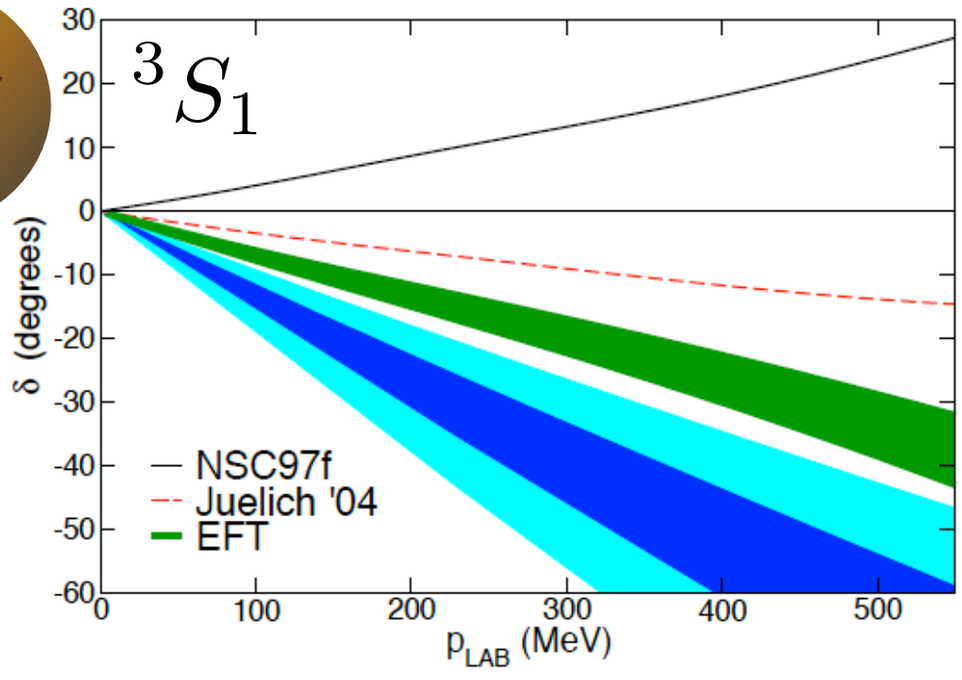
Jefferson Lab

HPC *is the third pillar of scientific research* in this program

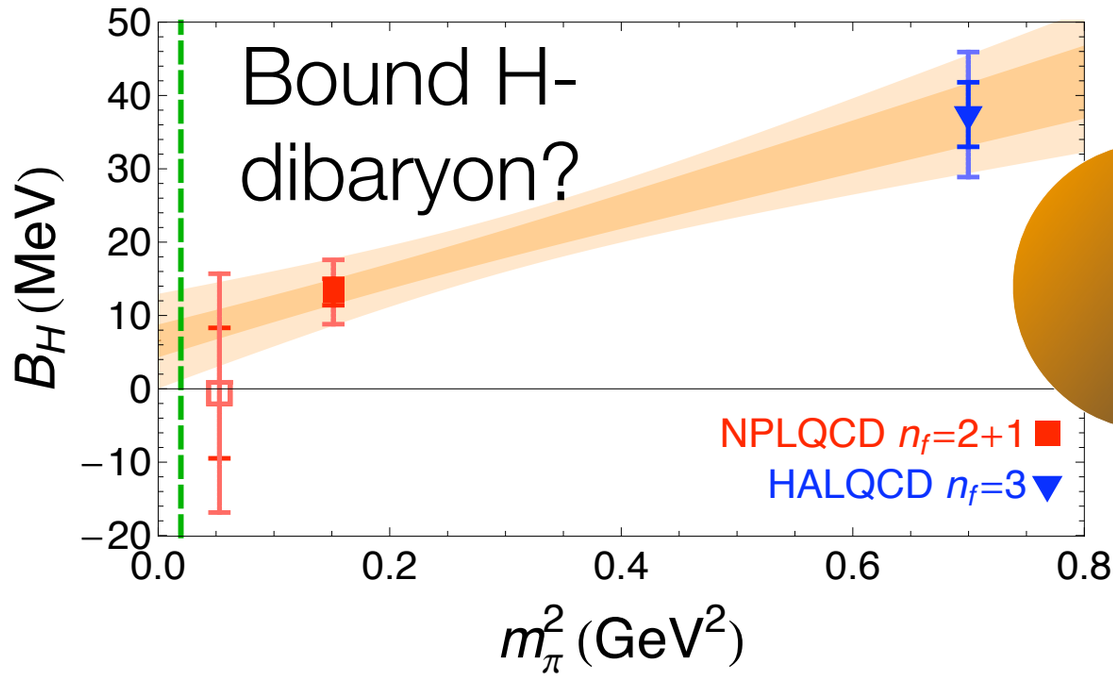
Hadron interactions can impact our understanding of neutron star evolution





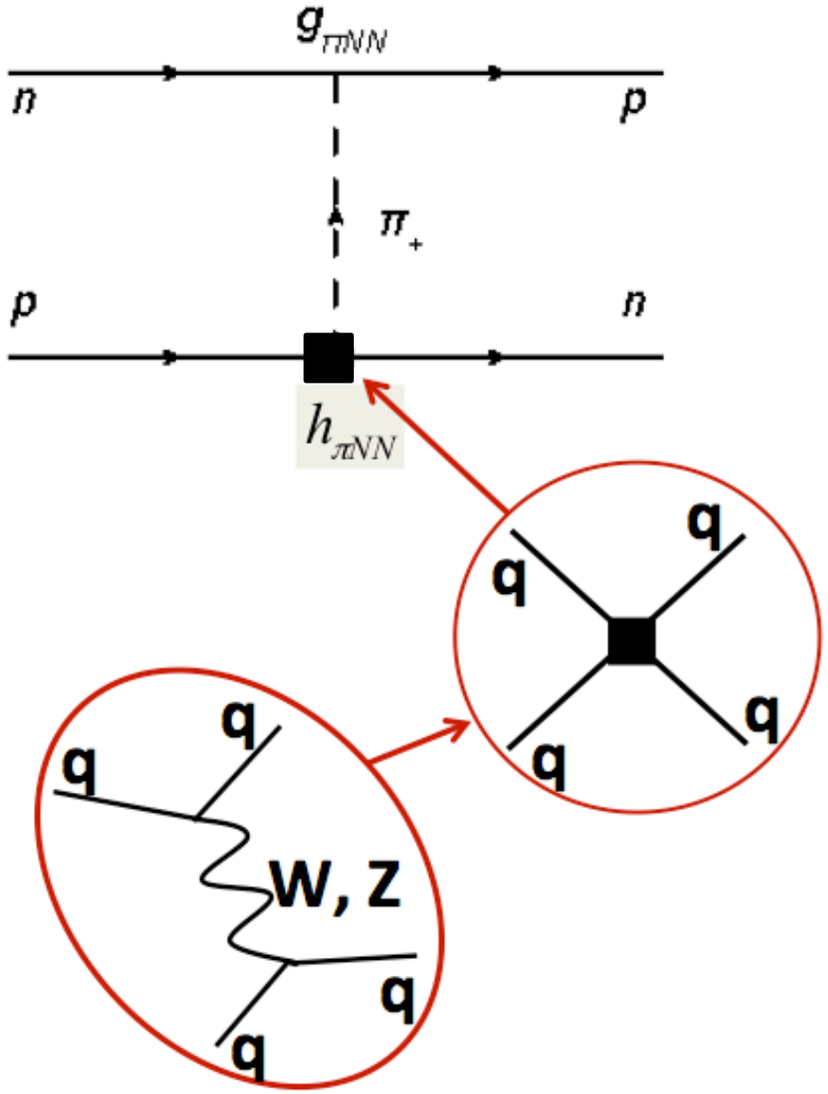


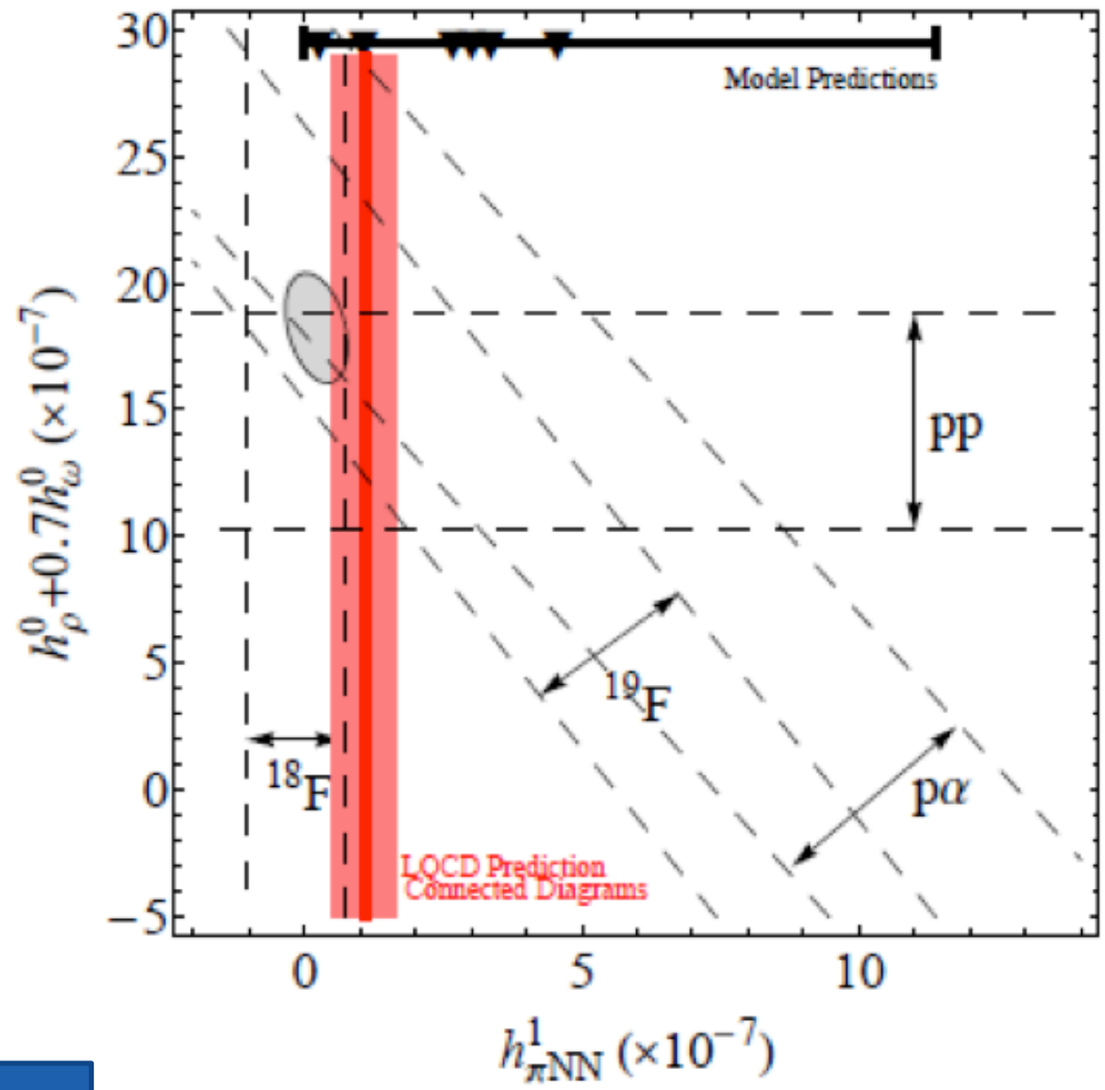
HP10 (2014): *"Carry out ab initio microscopic studies of the structure and dynamics of light nuclei based on NN and many-N forces & lattice QCD calculations of hadron interaction mechanisms relevant to the origin of the NN interaction."*



NPLQCD, arXiv:1204.3606, Phys.Rev.Lett. **106** (2011) 162001

The ‘weakest’ link in the standard model is now being tackled





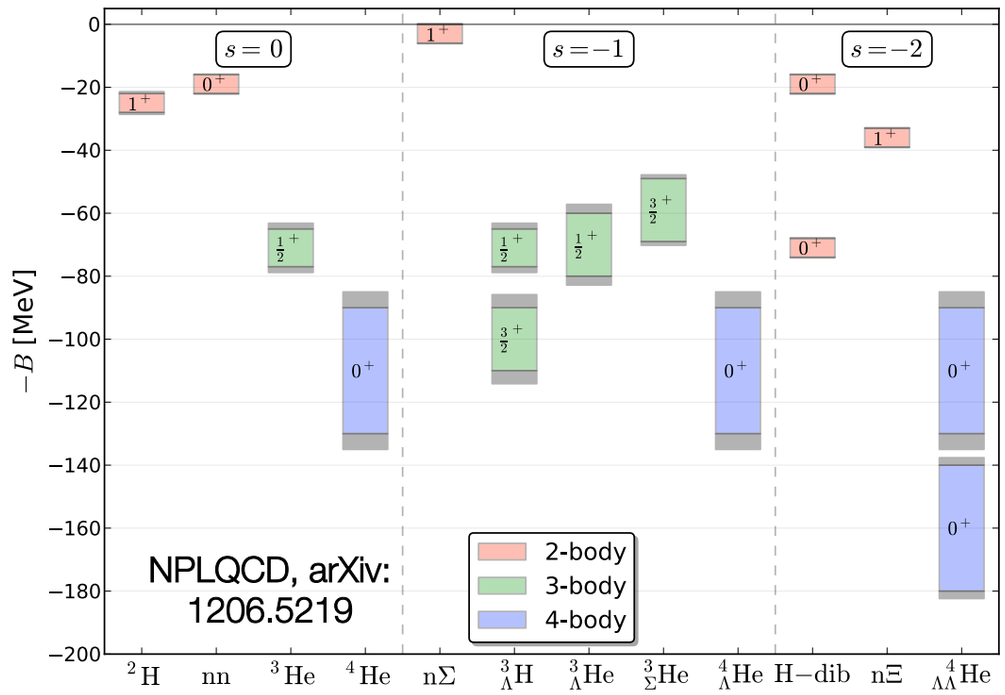
ΔI=0,2 channels will be possible with increased HPC resources

ΔI=1 nuclear parity-violating coupling from LQCD

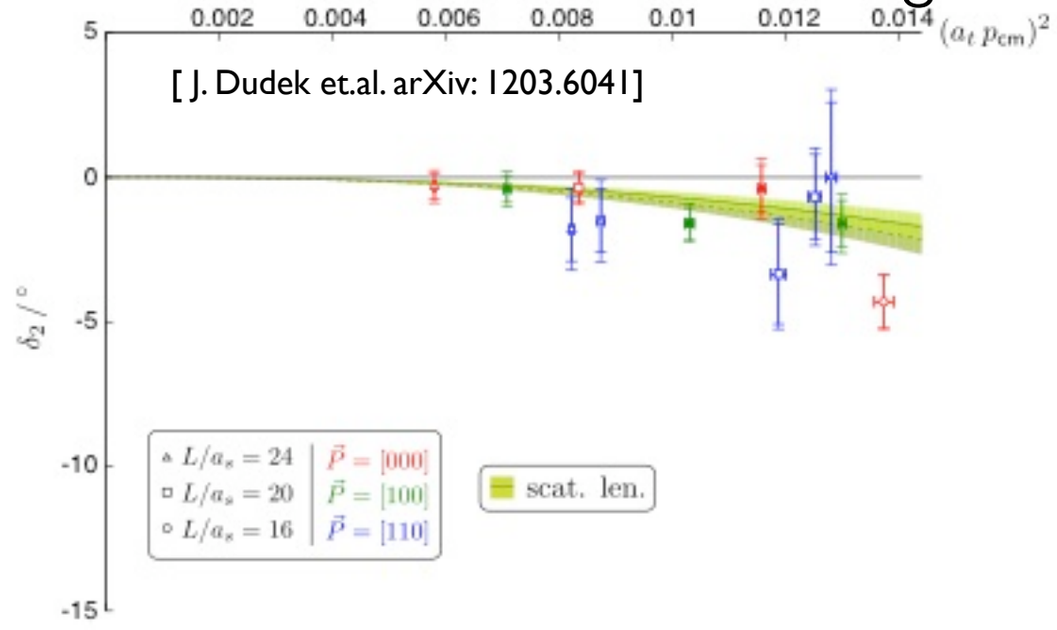
J. Wasem, Phys.Rev. C85 (2012) 022501

Other notable highlights

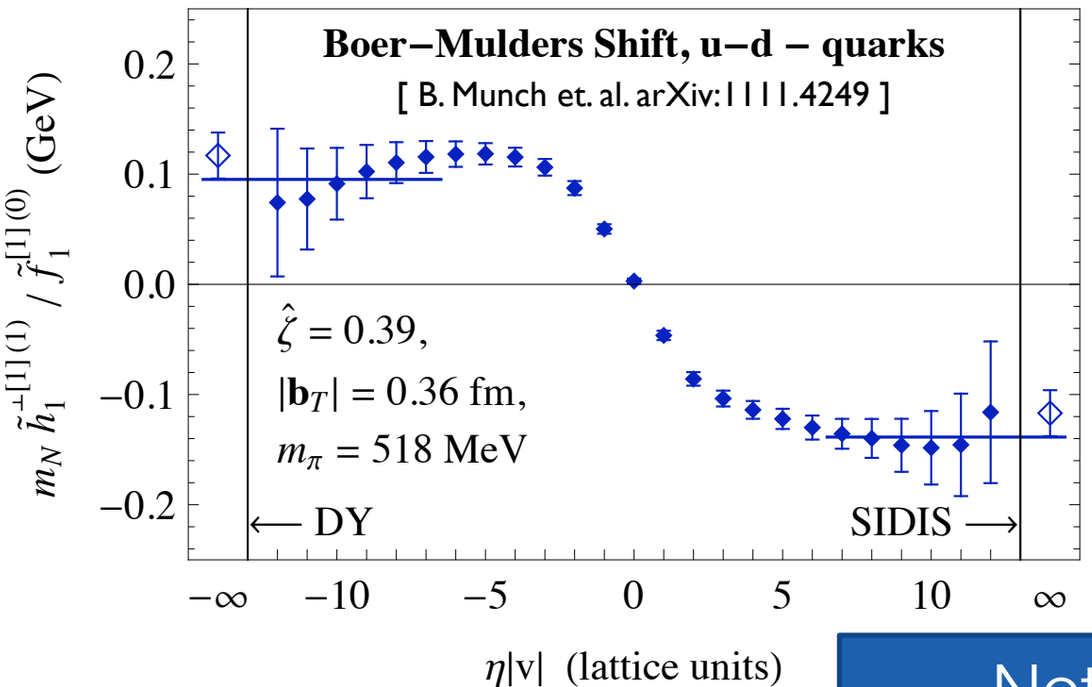
The spectrum of light nuclei @ SU(3) point



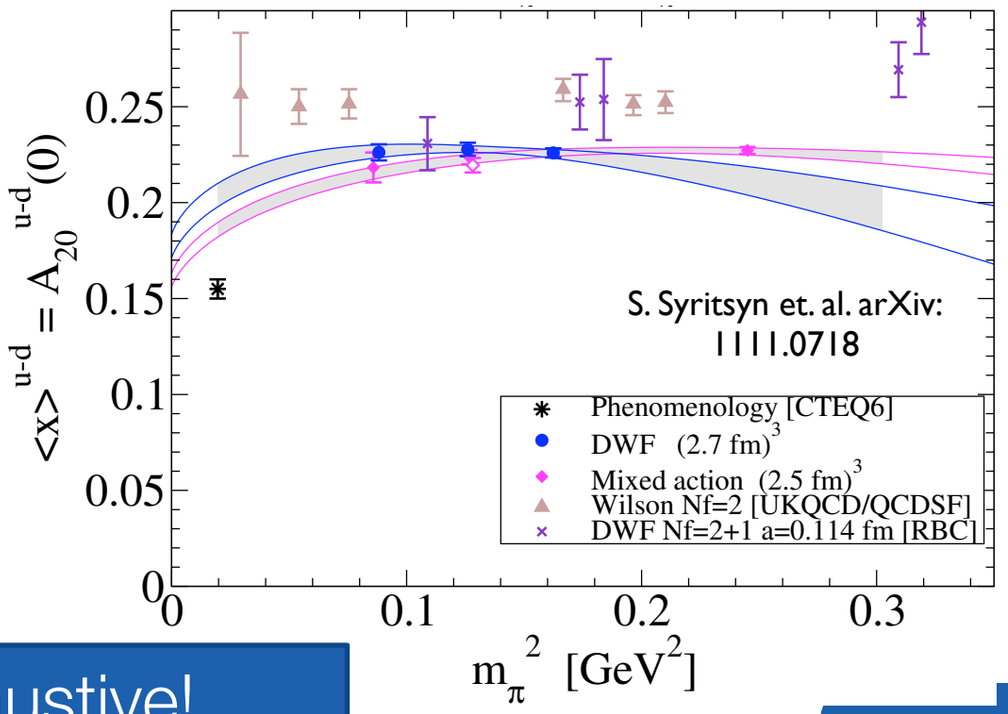
π-π I=2 D-wave scattering



Transverse momentum distributions

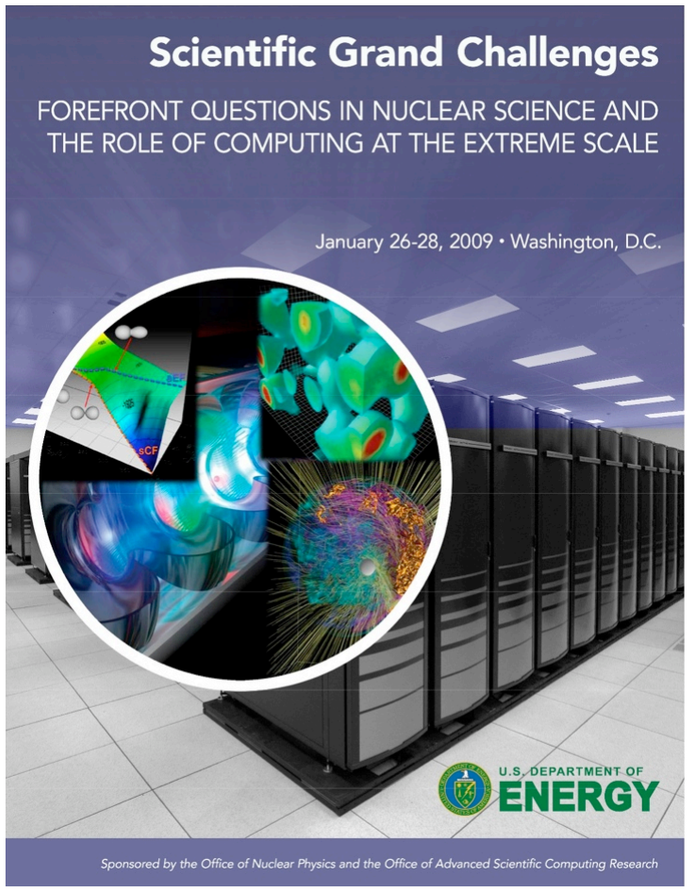


Generalized Parton Distributions



Not exhaustive!

ColdQCD has made great strides within the past few years

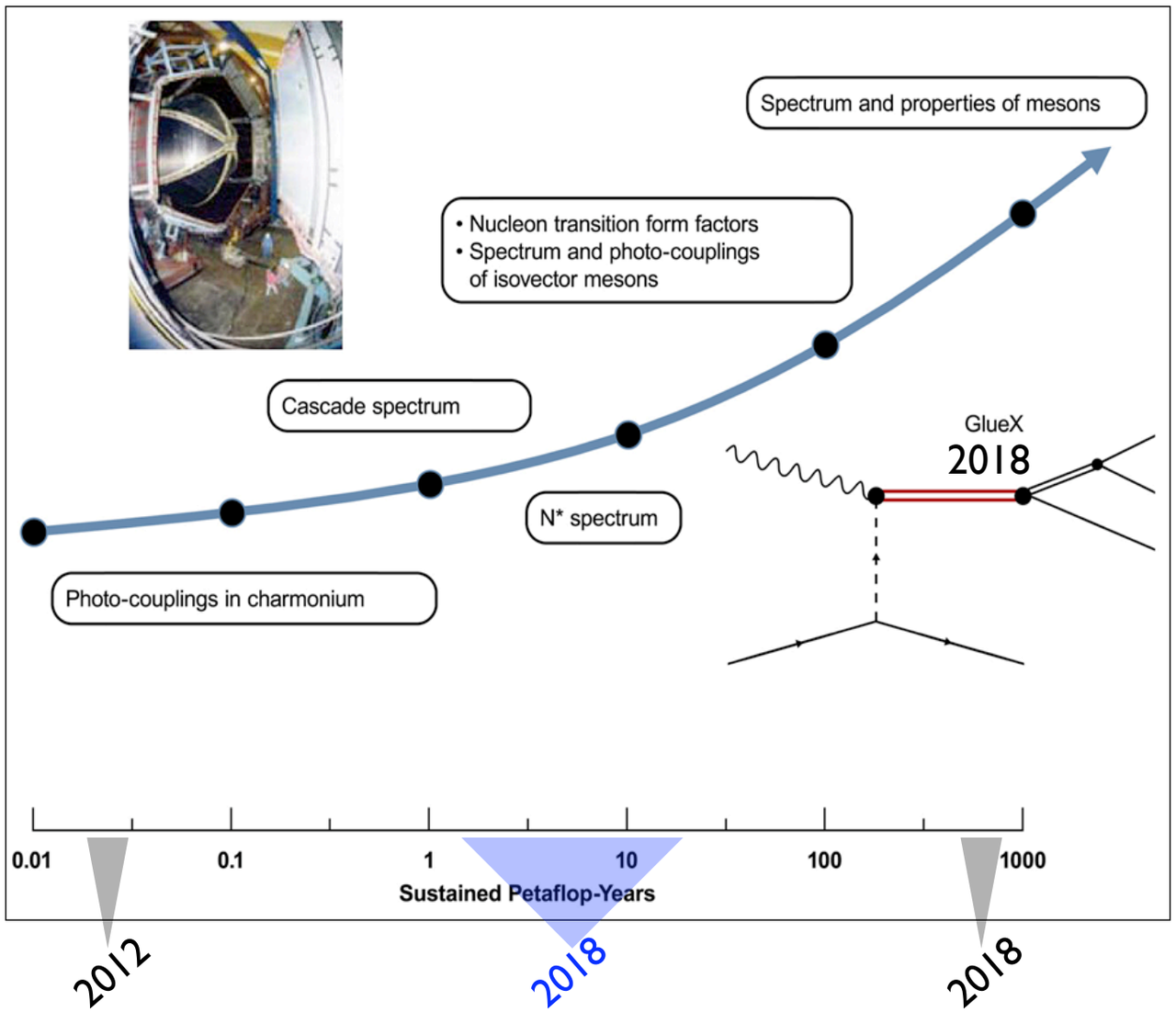


2009

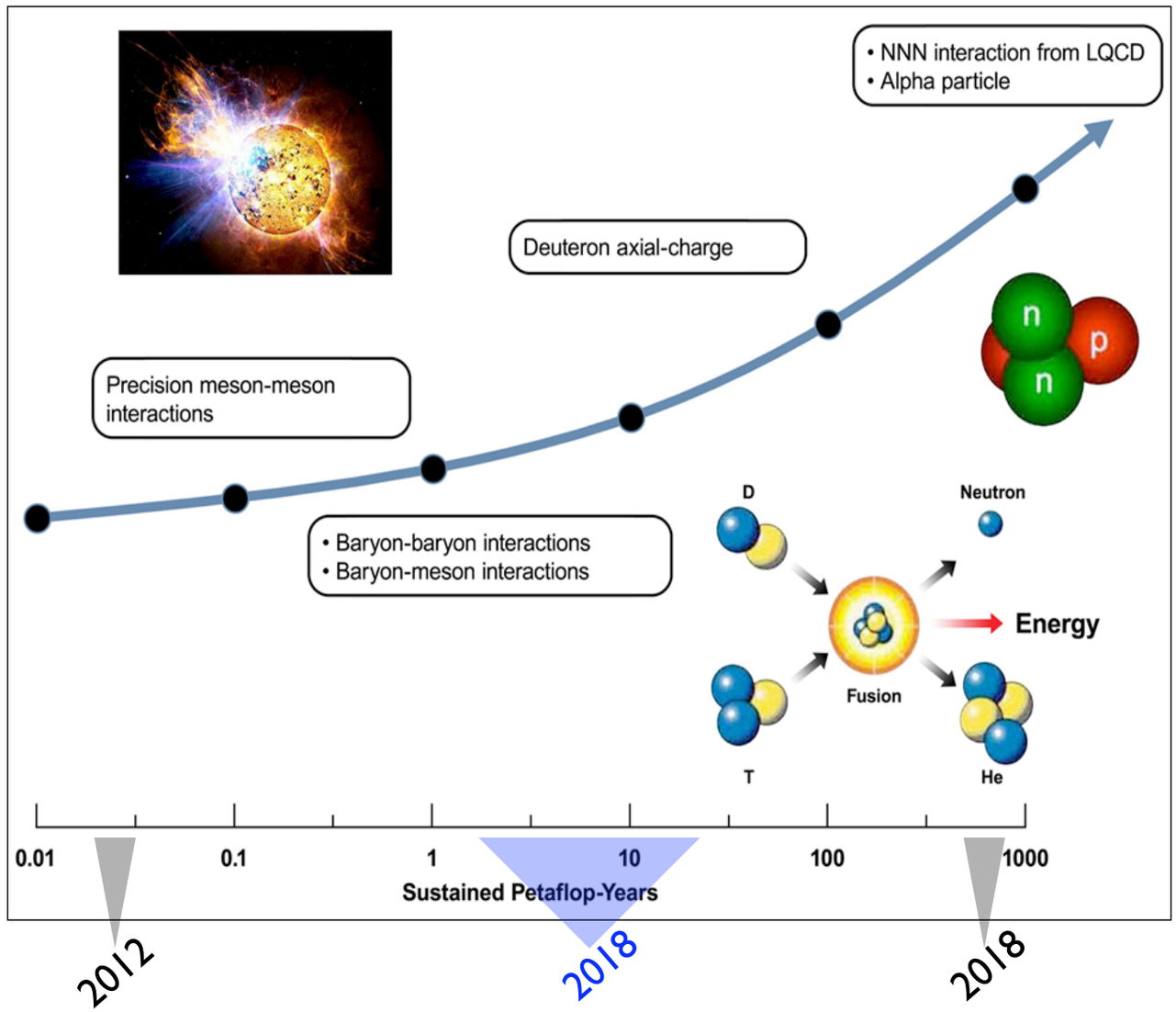
- Bound states from LQCD
- Moving beyond s-wave
- Probing A>4 systems
- First parity-violating calculations

Looking into the future

Hadron spectroscopy



Hadron interactions



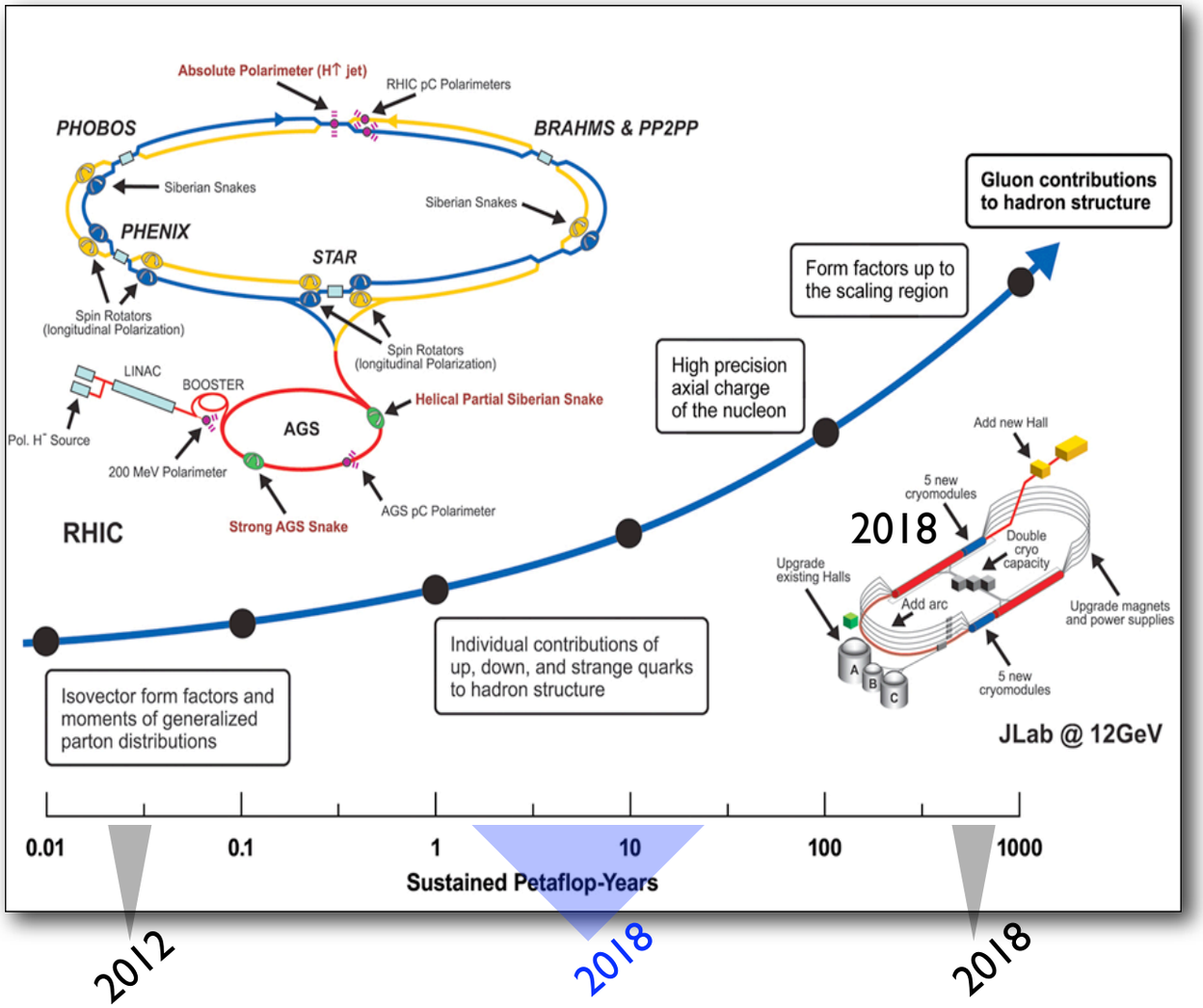
500 billion cpu-hrs
=
1/2 Petaflops-years

Desired trajectory

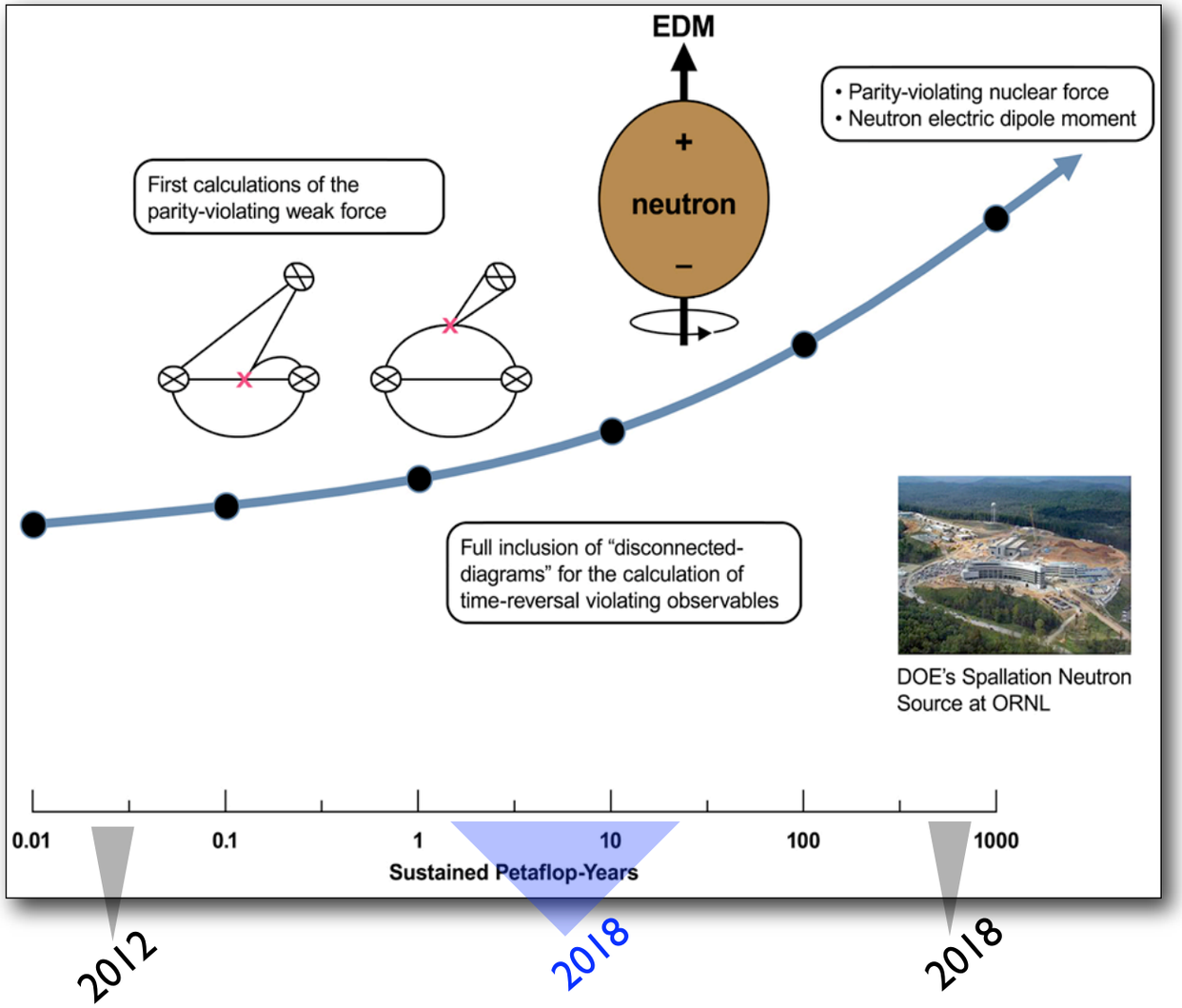
Flat trajectory (Moore's law)

Looking into the future

Hadron Structure



Fundamental Symmetries



Desired trajectory

Flat trajectory (Moore's law)

We're behind target, but the ship's not sinking (yet!)

- Increase access to resources (i.e. bigger allocations)
  - NP's own dedicated HPC facility???
- Continued investment in algorithm development

SciDAC
Scientific Discovery through Advanced Computing

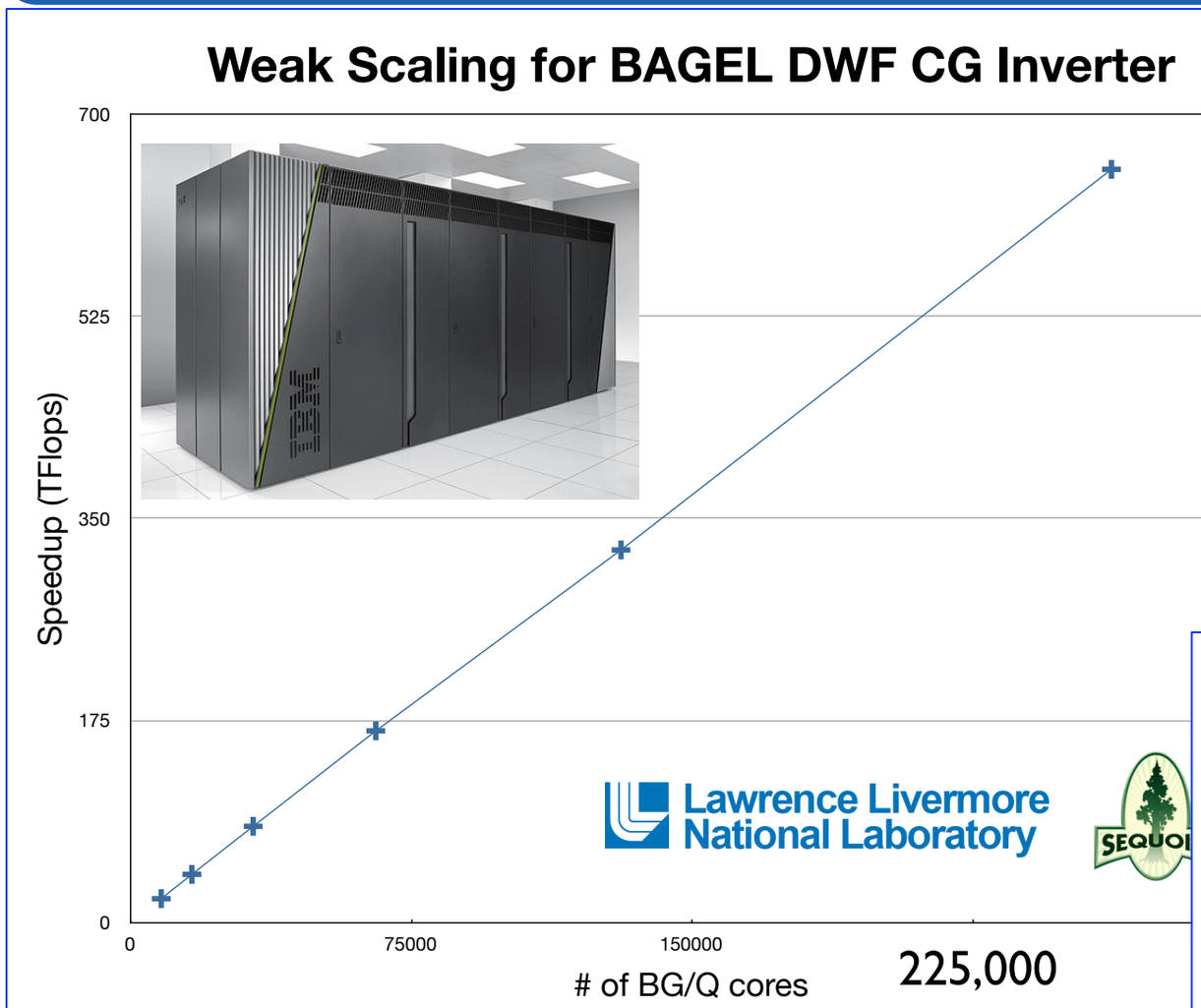
  - GPU multigrid/domain decomposition
  - Distillation
  - Recursive contraction routines
- We are a nascent field with lots of room for growth

Conclusion

- ColdQCD's theoretical program intimately tied to DOE experimental programs
- Directly addressing LRP/NSAC milestones, questions, and recommendations
- No surprise that ColdQCD's growth is correlated to HPC growth
- Experiencing growing pains (which is good!)
  - Lots of potential for growth, given adequate resources and support

Backup slides

So what's on the horizon?



Tests were performed with the STFC funded DiRAC facility at Edinburgh

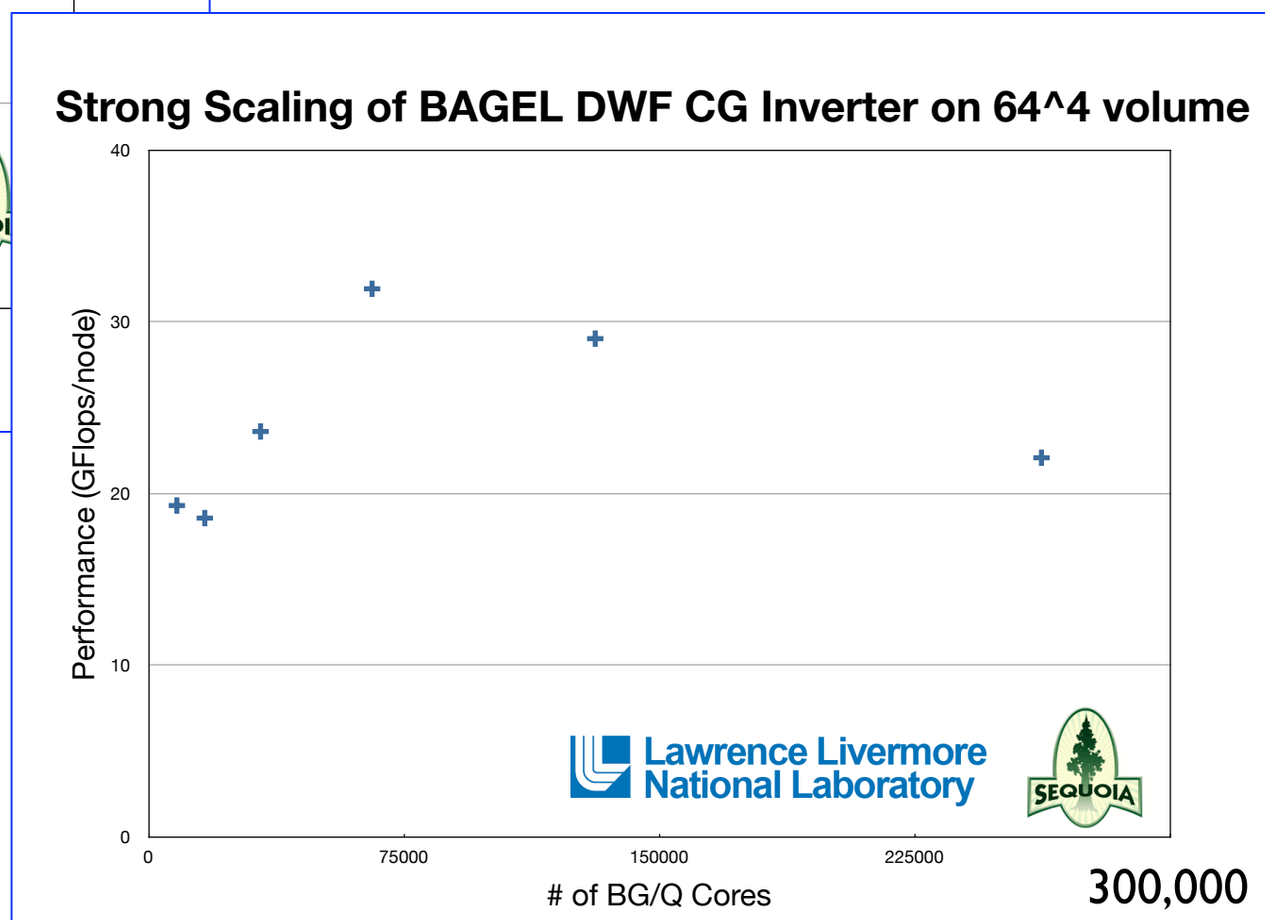
SEQUOIA BY THE NUMBERS

96 racks

98,304 nodes

1.6 million cores

20 petaflops

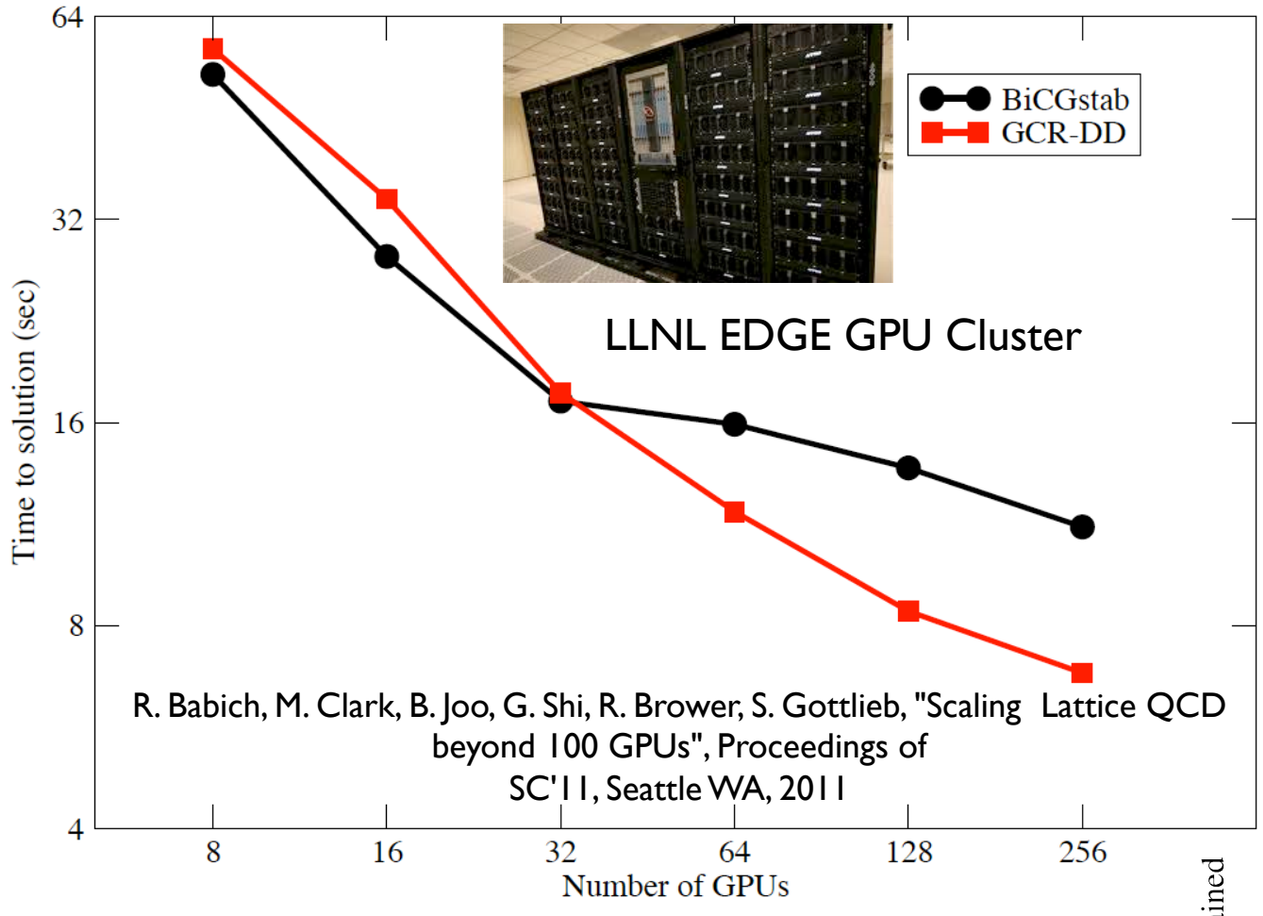


Tests were performed with the STFC funded DiRAC facility at Edinburgh

Figures courtesy of M. Buchoff

Studies performed by M. Buchoff, C. Schroeder, P. Vranas, J. Wasem

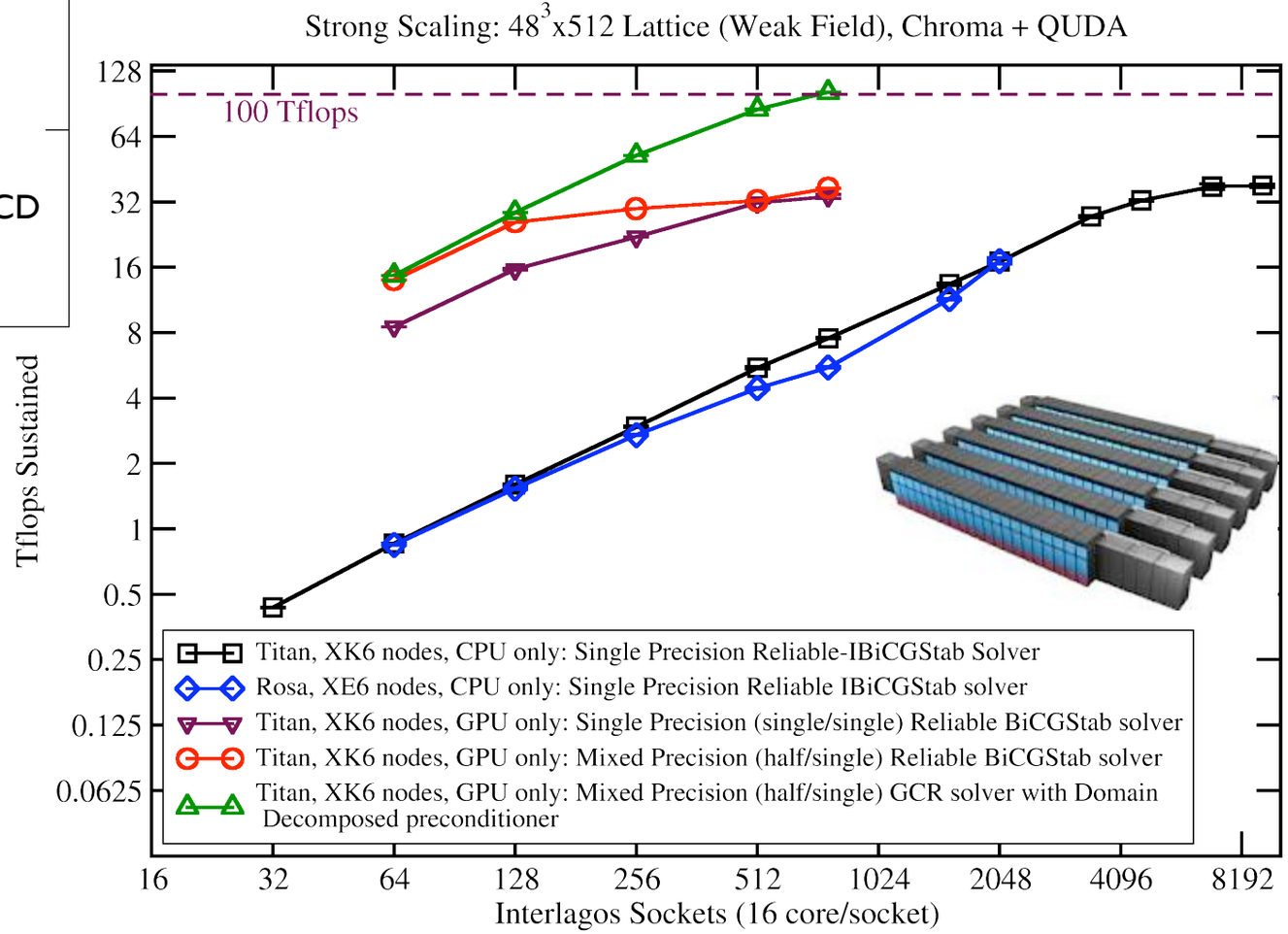
LQCD's computational orientation is not restricted to homogeneous systems



Figures courtesy of B. Joo

LQCD is at the forefront in developing scalable multi-GPU algorithms

Heterogeneous systems are ideally suited for particular aspects of LQCD



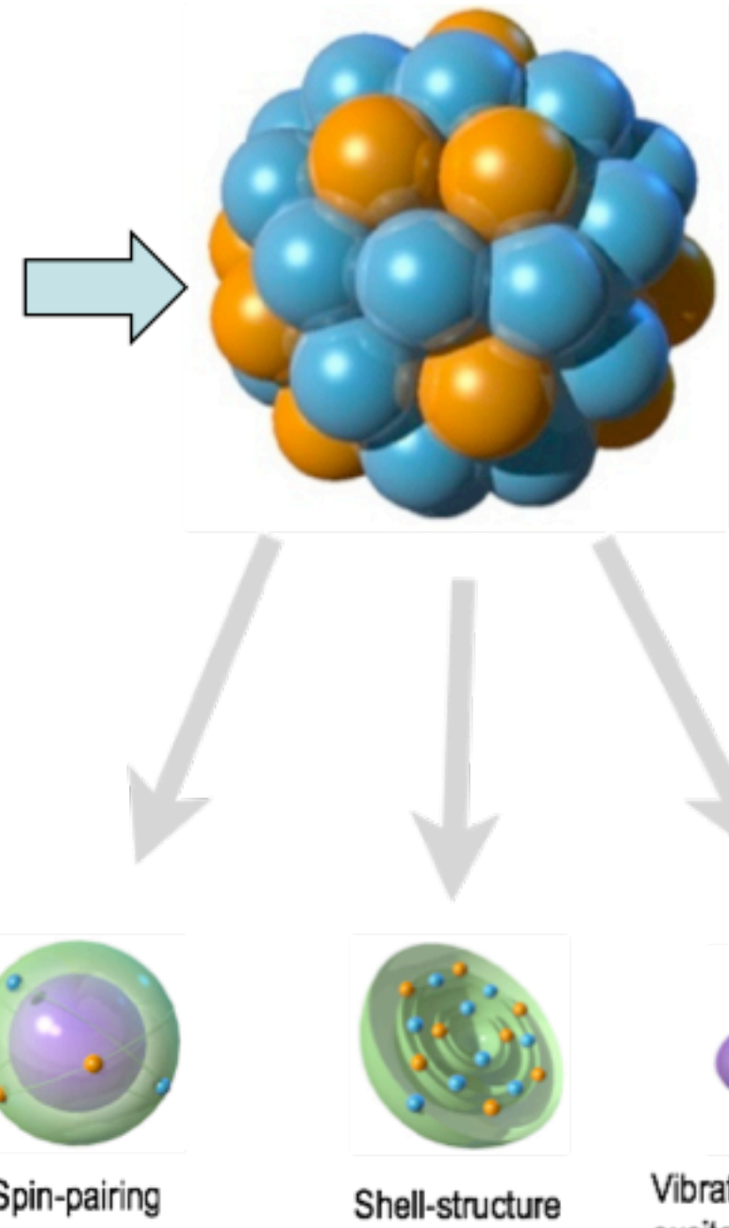
Studies performed by M. Clark, B. Joo et al.

We know the underlying theory of the nuclear force: QCD

Input parameters

$$\left[\begin{array}{c} g \\ m_u \\ m_d \\ m_s \\ e \\ G_f \end{array}\right]$$

$$\mathcal{L}_{\text{QCD}} + \text{ElectroWeak}$$



In principle, the 3-neutron force should be accessible from QCD