Nuclear Physics from Lattice QCD – Status and Future Perspectives

USQCD Collaboration, Spectrum Project

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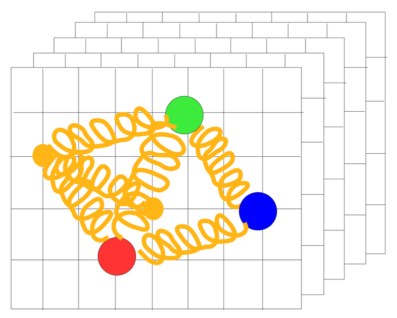
Introduction

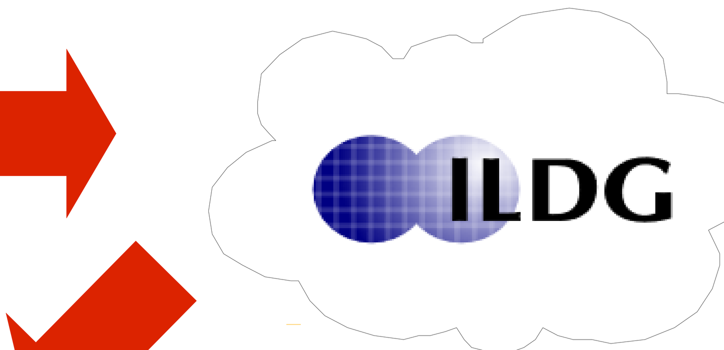
Lattice QCD allows *ab initio* calculations of quantities in the physics of strongly interacting particles (hadrons) that are necessary for the understanding of their spectroscopy, structure and interactions. Lattice QCD calculations are also needed as input to the combined analysis of available experimental data on the photoproduction of nucleon resonances which is a 2009 Nuclear Physics milestone in Hadronic Physics (HP) as well as to the measurement of the electromagnetic properties of low lying baryons which is an HP 2012 milestone. Lattice QCD calculations of the properties of exotic mesons are crucial to guide the experimental work of the Glue-X project which is a flagship component of the 12 GeV Upgrade at the Jefferson Lab. In this poster we report on the progress made by the Spectrum project of USQCD towards these goals under INCITE and consider future needs and challenges.

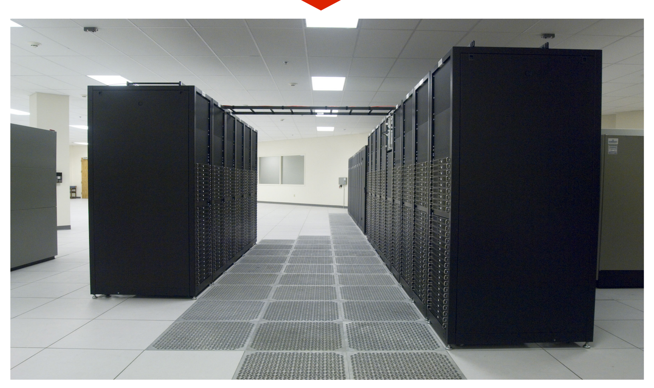
Lattice Calculations

Gauge field configurations are generated corresponding to bare parameters such as quark masses and other couplings. The configurations are snapshots of the QCD vacuum. This process is numerically intensive requiring leadership class facilities



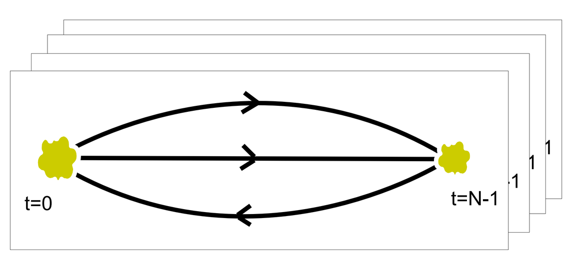
The configurations are archived and shared in the wold wide QCD community. E.g. Via the International Lattice Data Grid (ILDG)

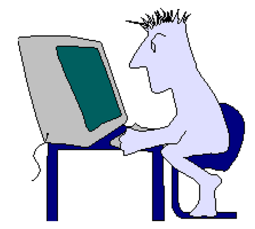




The configurations are analyzed to produce observables of interest – typically correlation functions for physical states. This takes place on smaller scale facilities such as USQCD clusters.

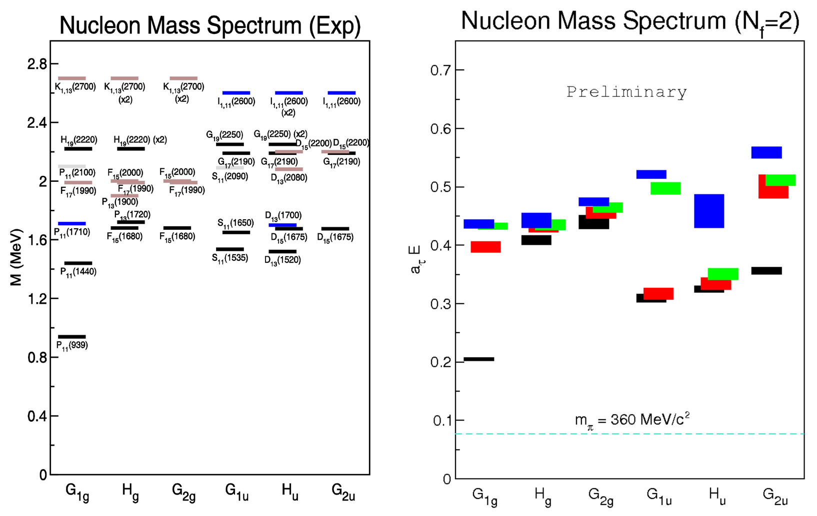
Finally observables are combined in statistical analyses to produce the scientific results.





Recent Results and Status

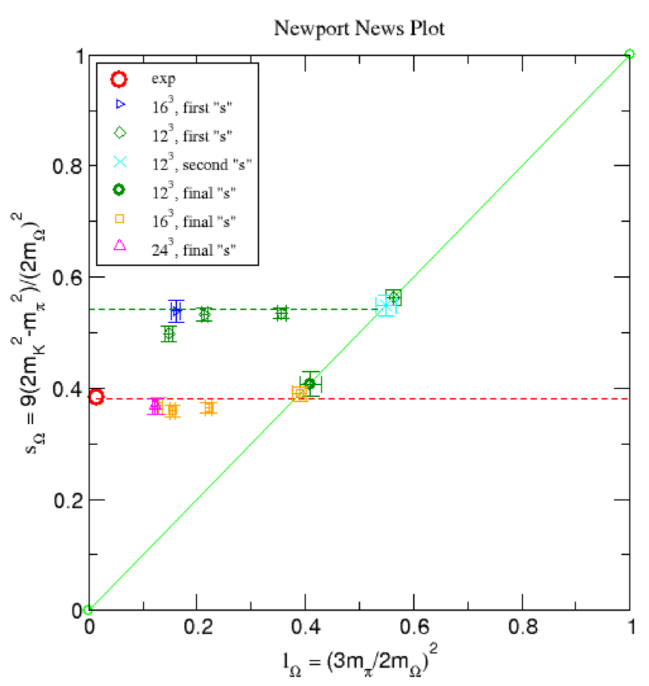
Hadron Spectrum with 2 Flavors of Sea Quarks



The low lying spectrum of hadrons from experiment (left) and a lattice QCD study with 2 flavors of dynamical quarks from (right). Excited states of the spectrum are clearly accessible, validating our method.

Data from INCITE'07, paper in preparation

Tuning the Strange Quark Mass for 2+1 Flavors of Quarks

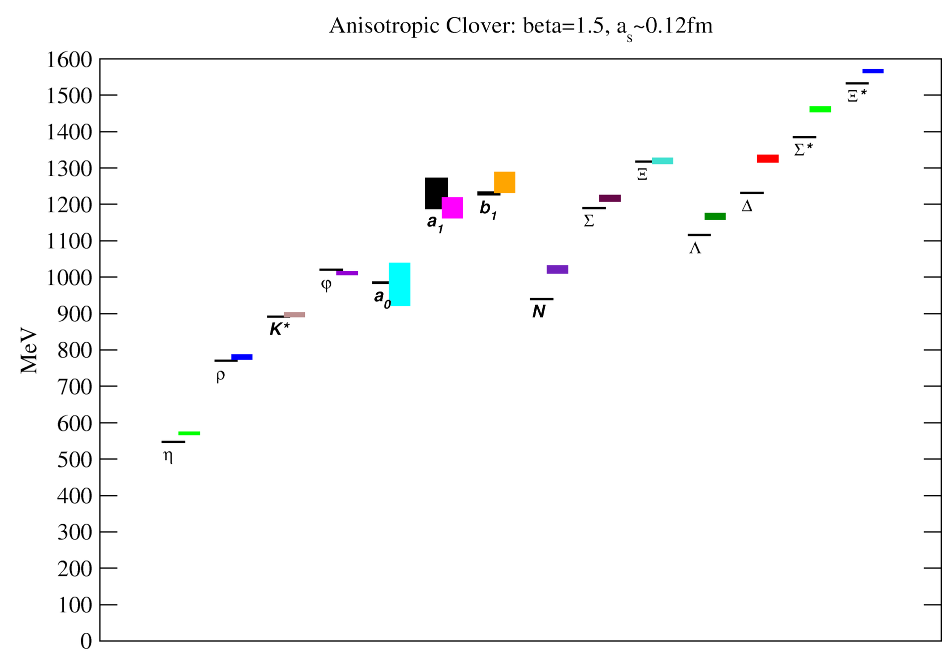


The *l* co-ordinate (horizontal axis) is proportional to the *light quark mass*; the *s* co-ordinate (vertical axis) is proportional to the *strange quark mass*, while remaining insensitive to the light quark mass to first order in chiral perturbation theory. The red circle is where the *(l,s)* coordinates are at their physical value. The *(l,s)* co-ordinates are *insensitive to the lattice spacing*, which varies with bare parameters, making them *ideal coordinates for extrapolations* along the dashed red line to the physical point.

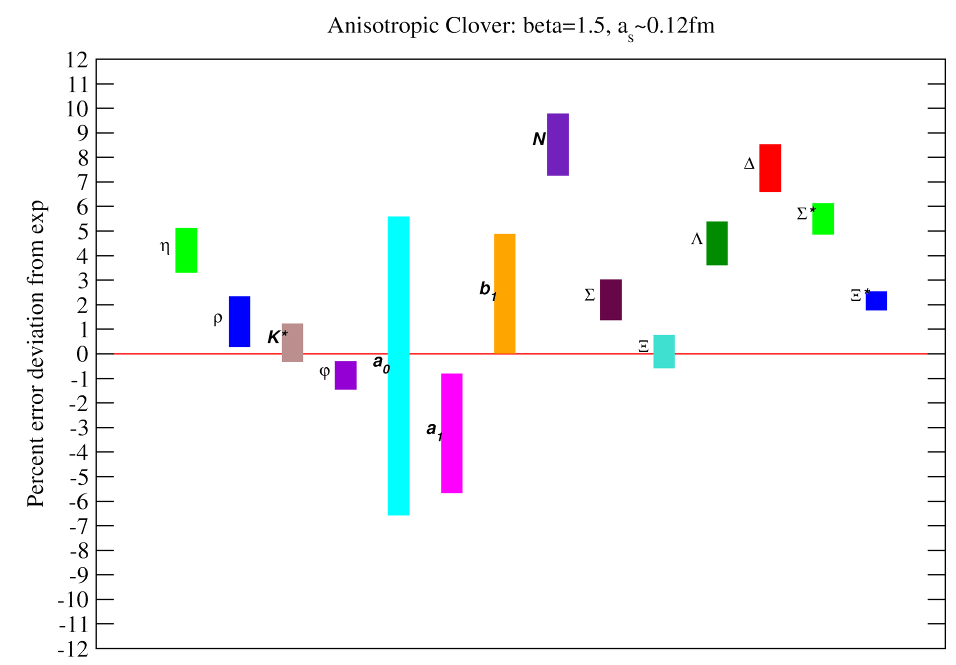
Data from INCITE 2008, paper in preparation

Low lying Hadron Spectrum with 2+1 Flavors of Sea Quarks

The upper graph shows the masses of the ground state mesons and baryons extrapolated to physical sea quark masses using the *(l,s)* coordinates from above. Black rectangles correspond to the experimental values of the masses.



The lower graph shows that the deviation of our results from experiment is within 5%-6% in most cases and within 10% for all cases.



The ability to correctly tune our strange quark mass, and the extraction of the ground state spectrum is a major milestone for us. Analysis of excited states and other observables is currently in progress

Data from INCITE'08, paper in preparation

Future Needs, Challenges

Computational Cost of Gauge Generation

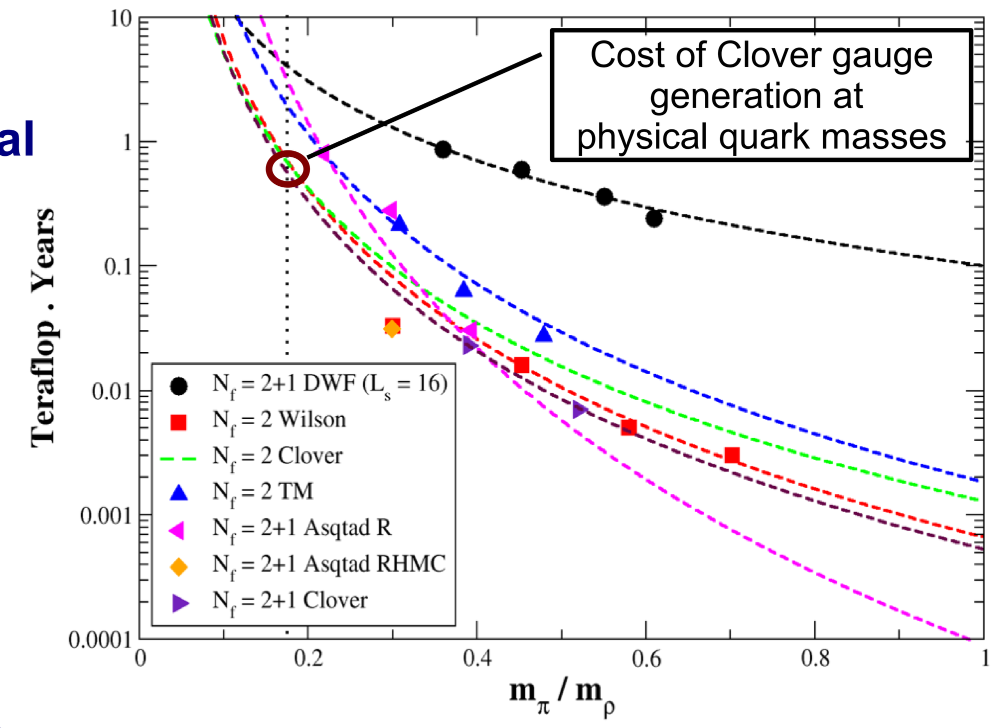


Figure from Mike Clark, Lattice 2006 plenary arXiv:hep-lat/0610048

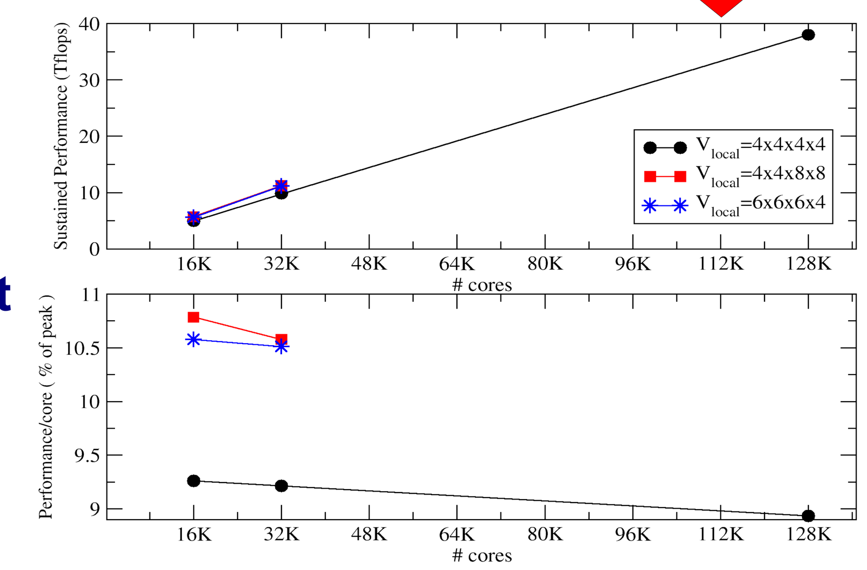
"Berling Wall" plot showing the cost to generate *1000 independent gauge configurations* on a 24^3x40 lattice. At the physical limit the cost is O(1) Tflop-year.

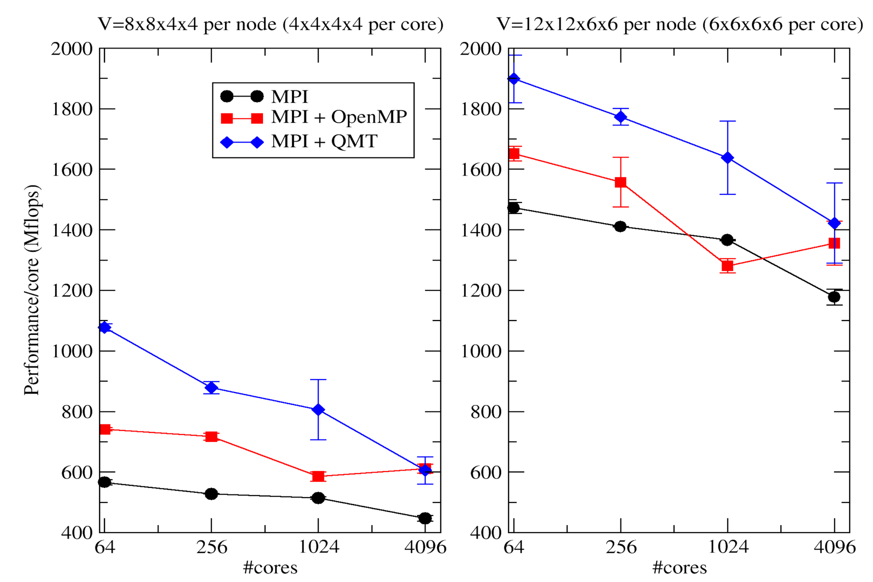
Our lattices are 24^3x128 to 48^3x256. Naïve volume scaling drives the cost up to 50-136 Tflop-years.

1-3 years at this rate, per ensemble

Scaling Challenges

Weak scaling of our Multi-Shift Conjugate Gradients solver on the BlueGene/P at ANL in double precision (right). The scaling is almost linear to within 1% of peak up to 128K cores. Strong scaling effects can be seen between the 4^4 local volume and the other two cases.





Scaling of our operator to 4096 cores on Jaguar (left). We see improvements from threading with our QMT library. The left/right panels show a strong scaling effect. We are working with Cray to improve scaling of this operator on a larger number of cores

Summary and Outlook

The USQCD collaboration vigorously pursues computer time through INCITE and Early User Periods. The allocations through INCITE have been critical to the USQCD community in general, with the time at the NCCS ORNL having been crucial to the USQCD Spectrum collaboration in particular. Through INCITE we are meeting our project milestones and building relationships between ourselves, the leadership computing centers and computer vendors. We look forward to carrying on with this work through future INCITE and Early User allocations in order to carry out our scientific mission and deliver our DOE milestones.

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