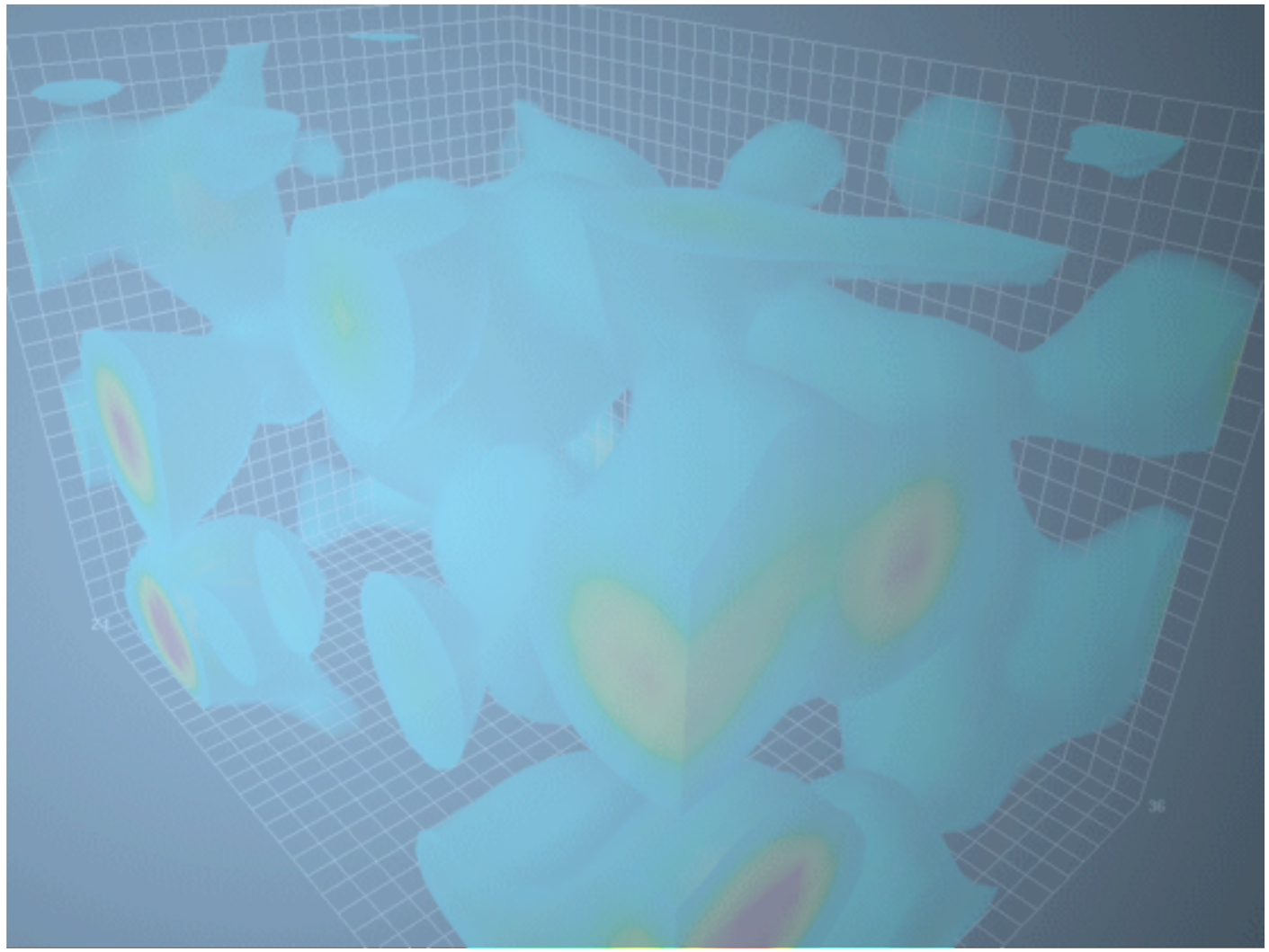
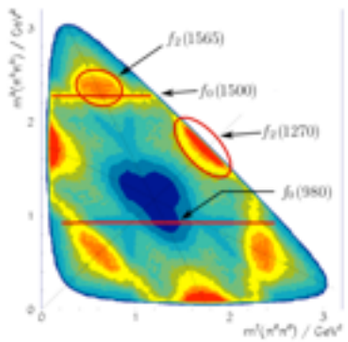
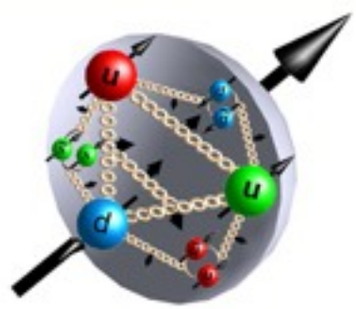
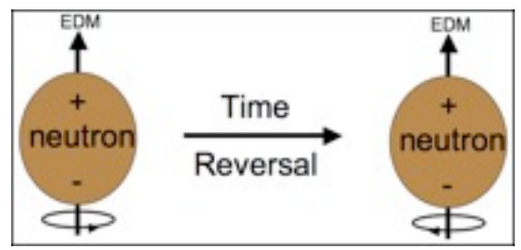
OAK RIDGE
National Laboratory





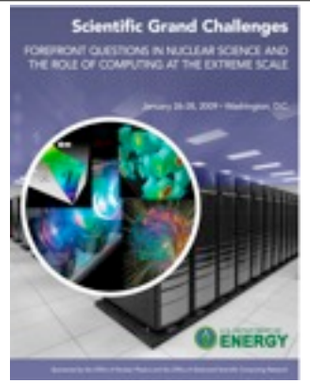




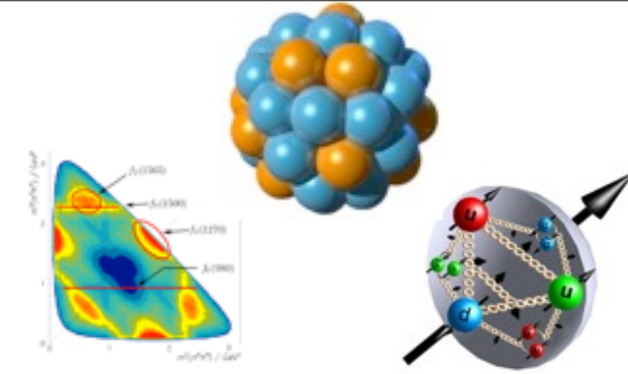
Cold Nuclear Physics

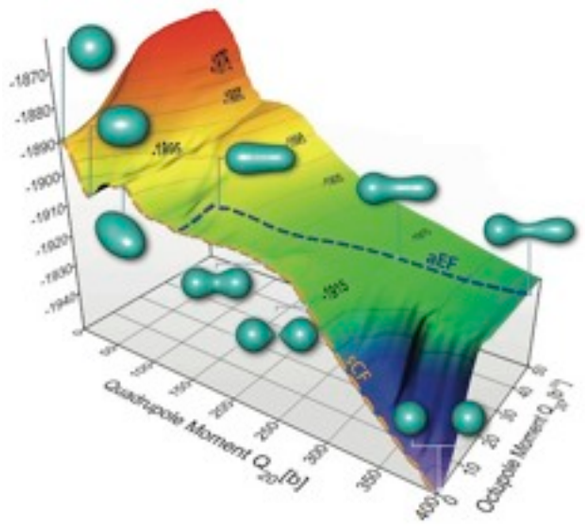
Structure, Spectrum and Interactions of Hadrons

Lattice QCD
Oak Ridge National Laboratory
April 29, 2013



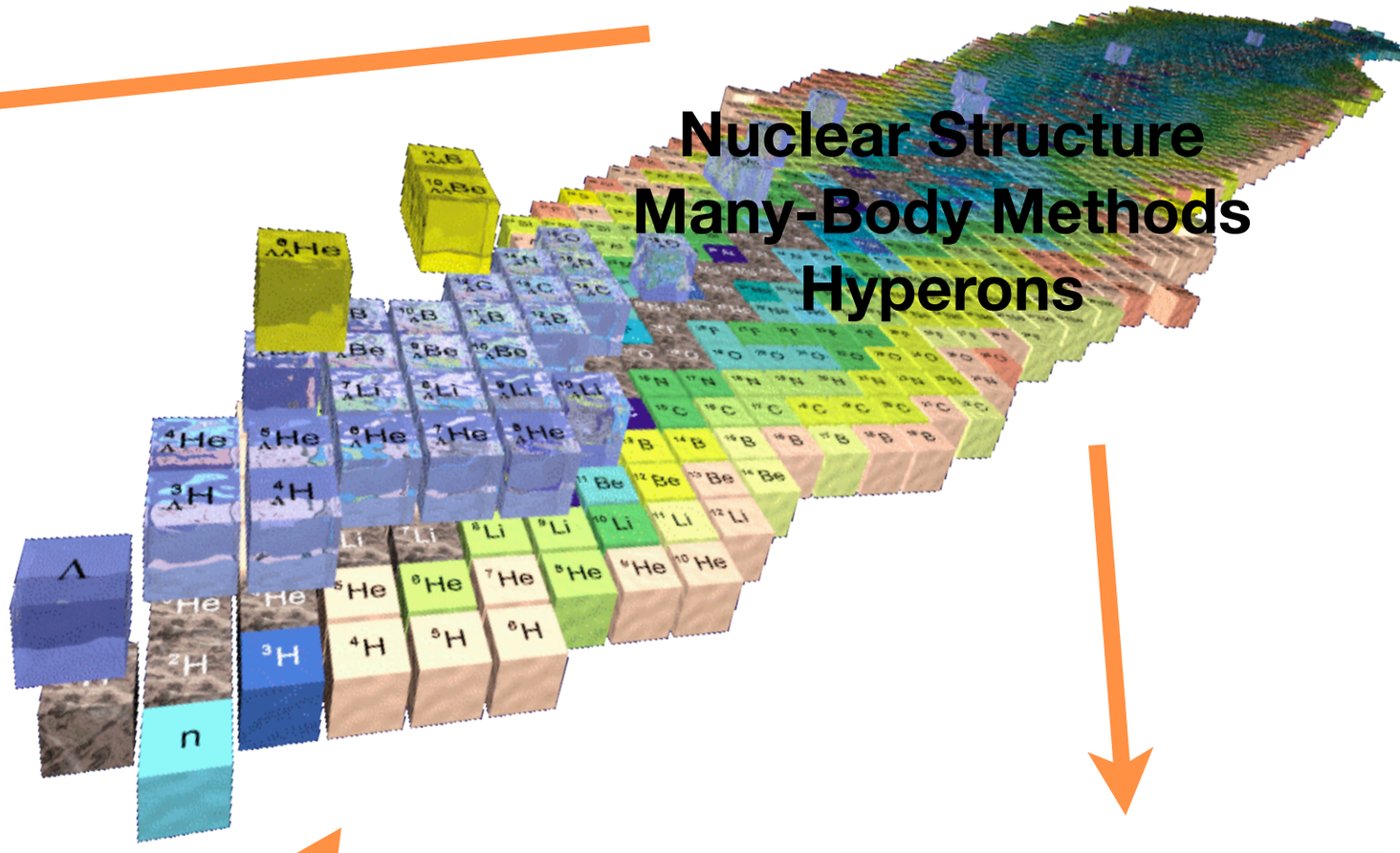
Science Challenge



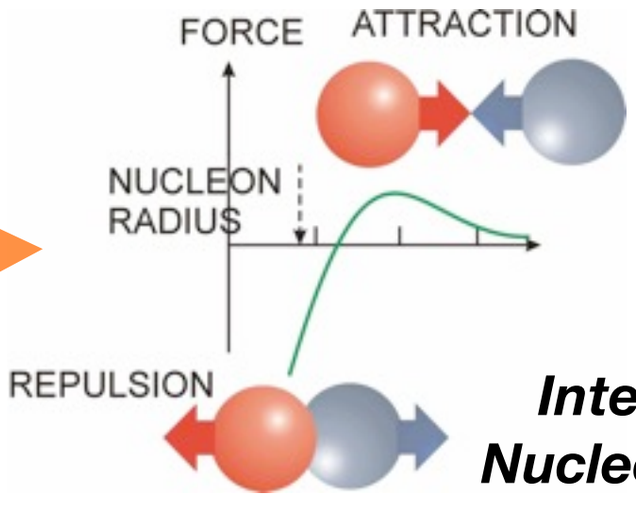


Spectrum and Structure of the Nucleon

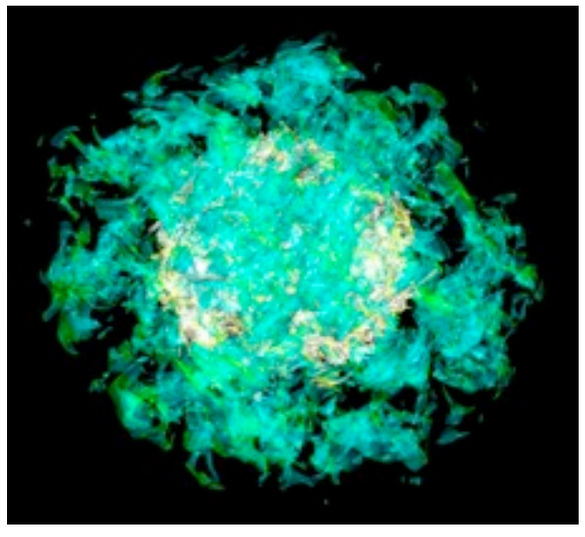
Nuclear Structure
Many-Body Methods
Hyperons

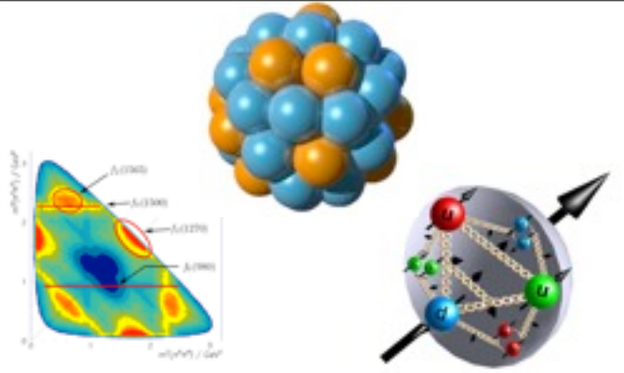


Solve QCD



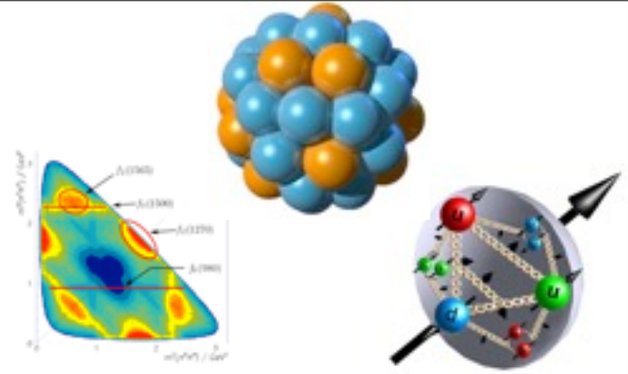
Interactions of the Nucleon and Hyperons



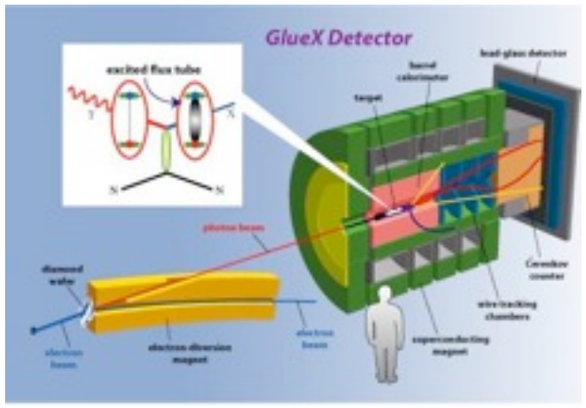


USQCD Program in

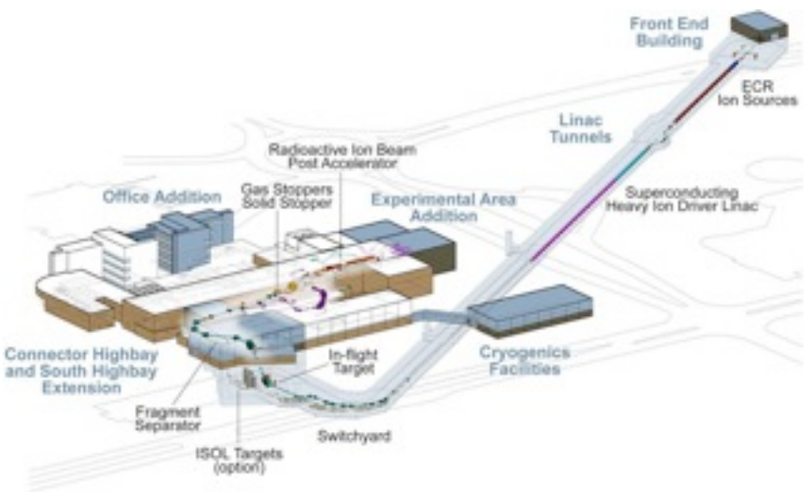
Structure, Spectrum and Interactions of Hadrons



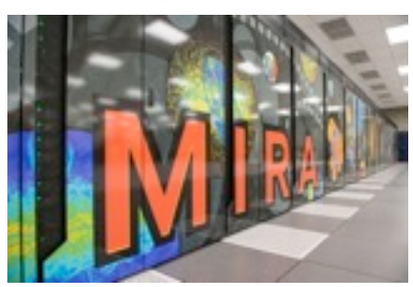
- Closely aligned with major NP projects
  - JLab (12 GeV upgrade) - Spectrum and Structure
  - FRIB - Interactions
  - ORNL, LANL - Fundamental Symmetries
  - Nuclei - nuclear many-body collaboration

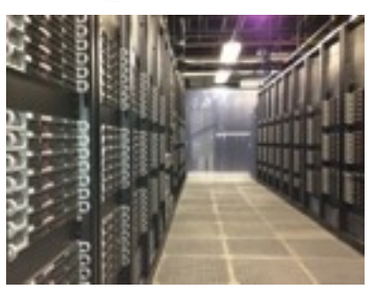


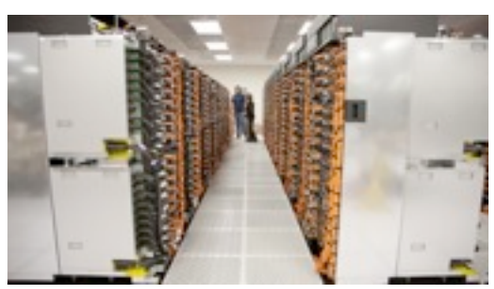
- Closely tied to NSAC Milestones
  - HP 3, 9,10, 15
  - FI 15

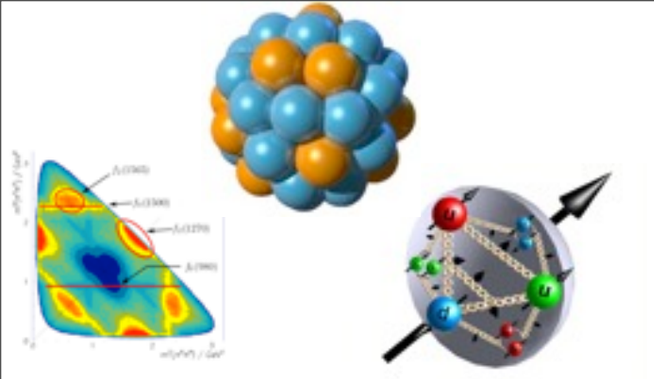


- Current : ~5 Pflop-yrs integrated resources 2013-2018









Relevant NSAC Milestones Status as of 2008/2009

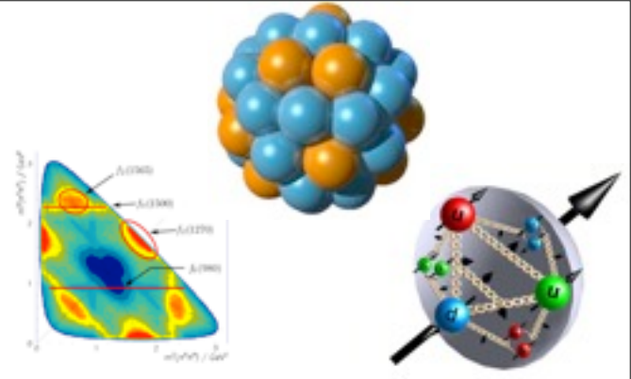
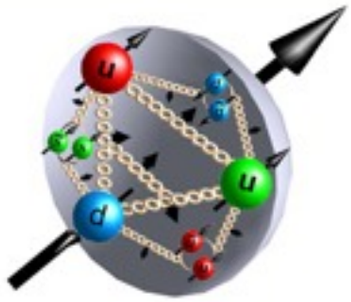


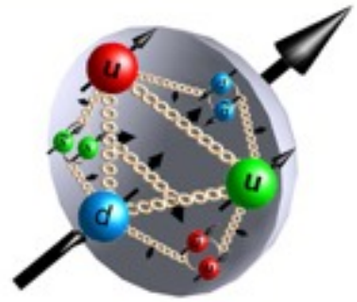
Table 4: Milestone Progress in Hadronic Physics

Year	Milestone	Complete?	Status Assessment
2009 HP3	Complete the combined analysis of available data on single π, η, and K photo-production of nucleon resonances and incorporate the analysis of two-pion final states into the coupled-channel analysis of resonances.	No	Expect to Not Achieve Fully
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.	No	Expect to Exceed
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 origin of the nucleon-nucleon interaction.	No	Expect to Achieve
2018	HP15 (new)	The first results on the search for exotic mesons using photon beams will be completed.	
2020	FI15 (new)	Obtain initial results from an experiment to extend the limit on the electric dipole moment of the neutron by two orders of magnitude	

(2008)

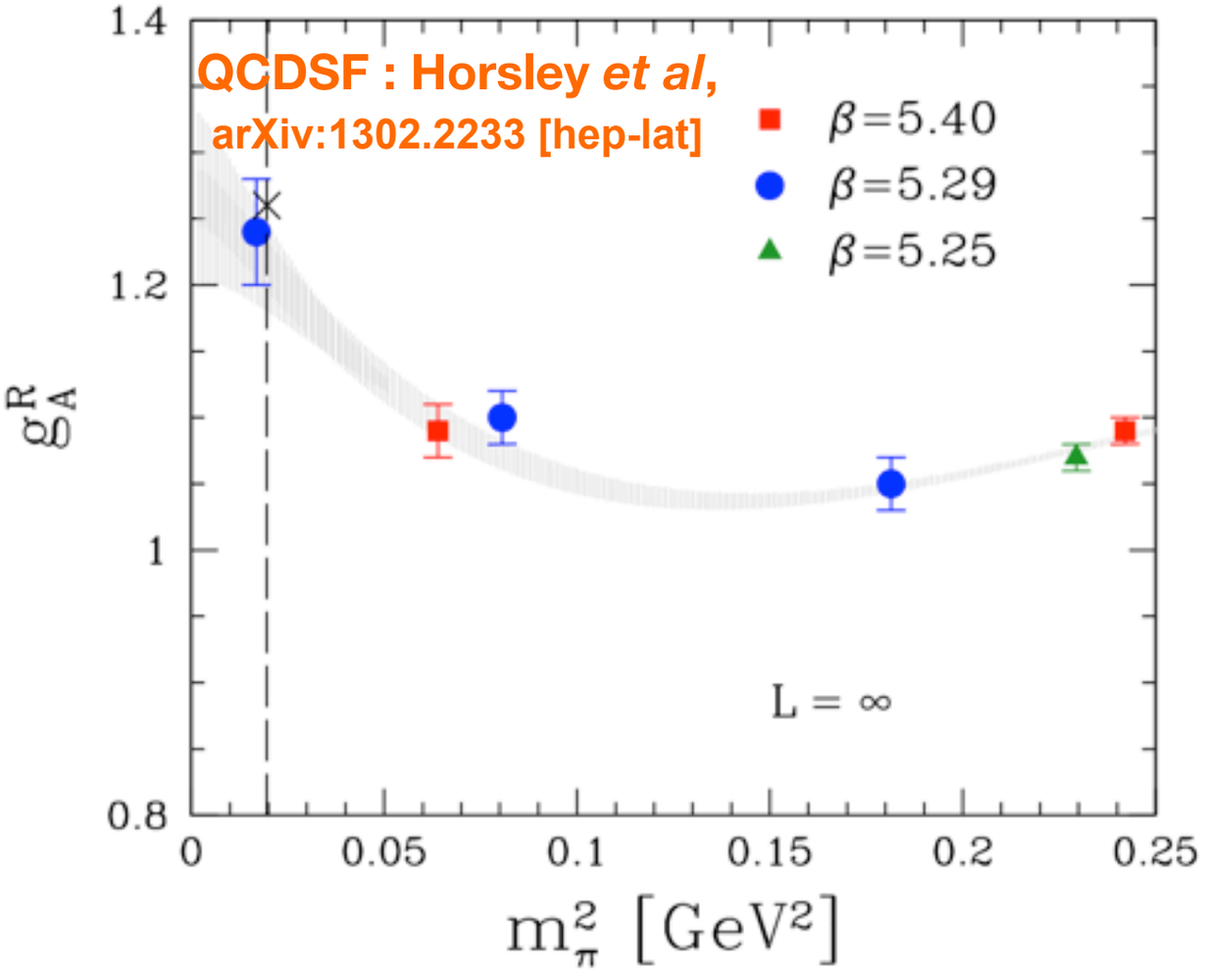


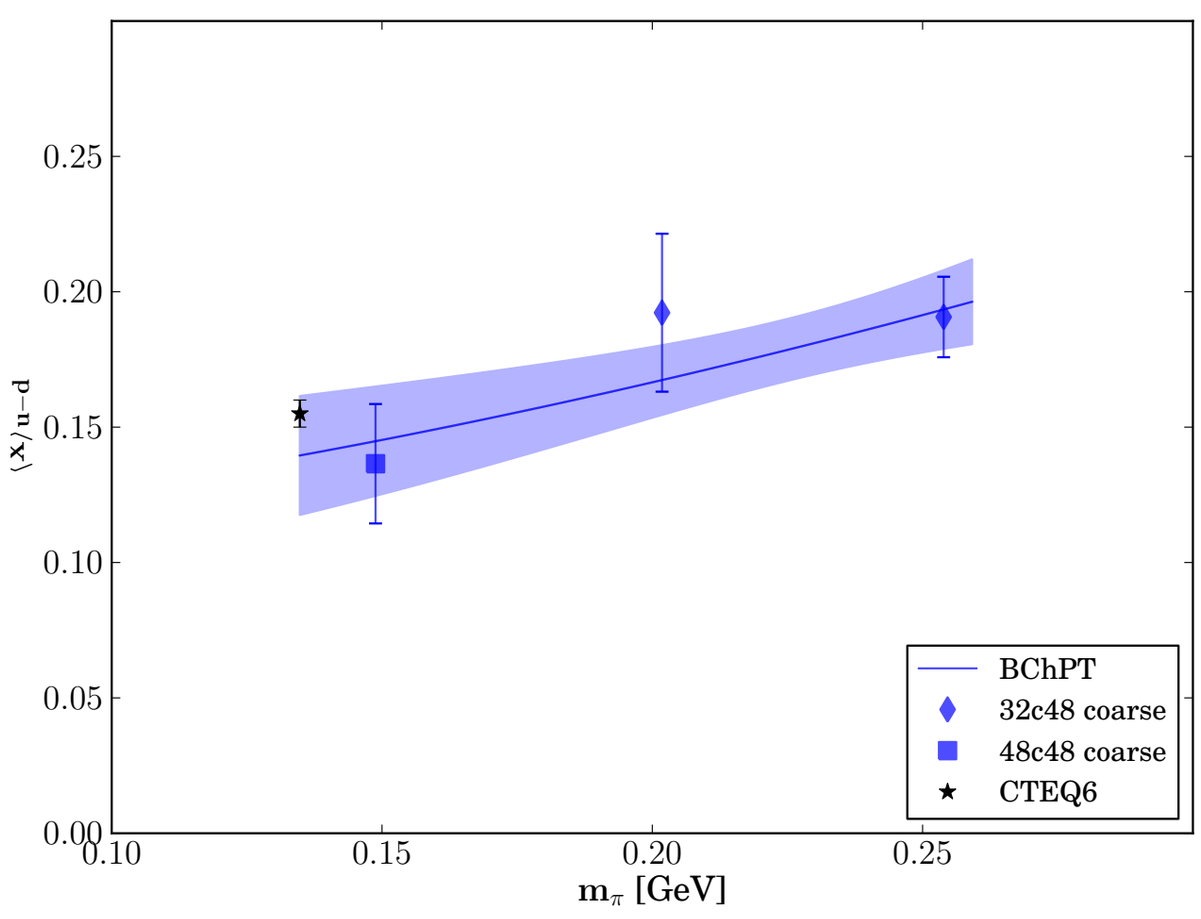
Structure

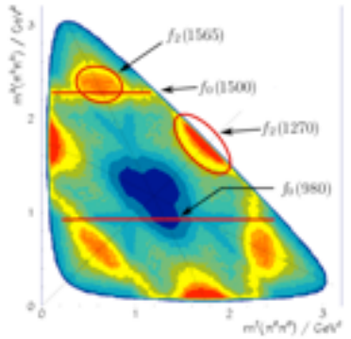


- g_A and other $q^2=0$ matrix elements
- $\langle x^n \rangle$
- charge and magnetic radii, FF's, etc

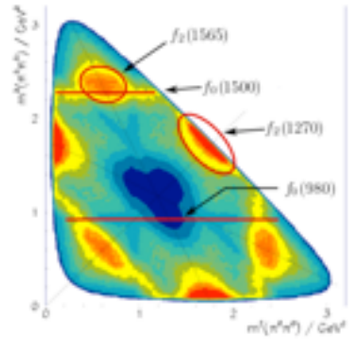
Precision is needed
(complete uncertainty quantification)



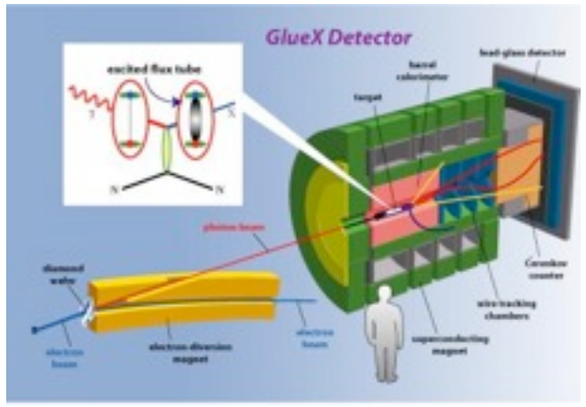


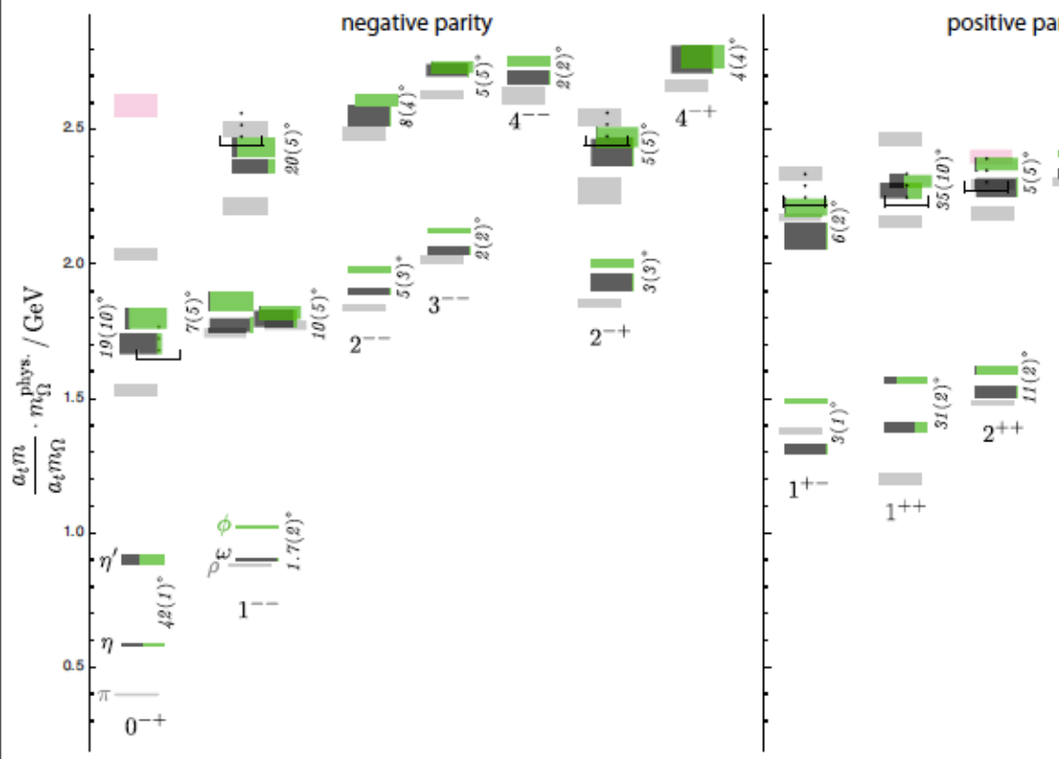


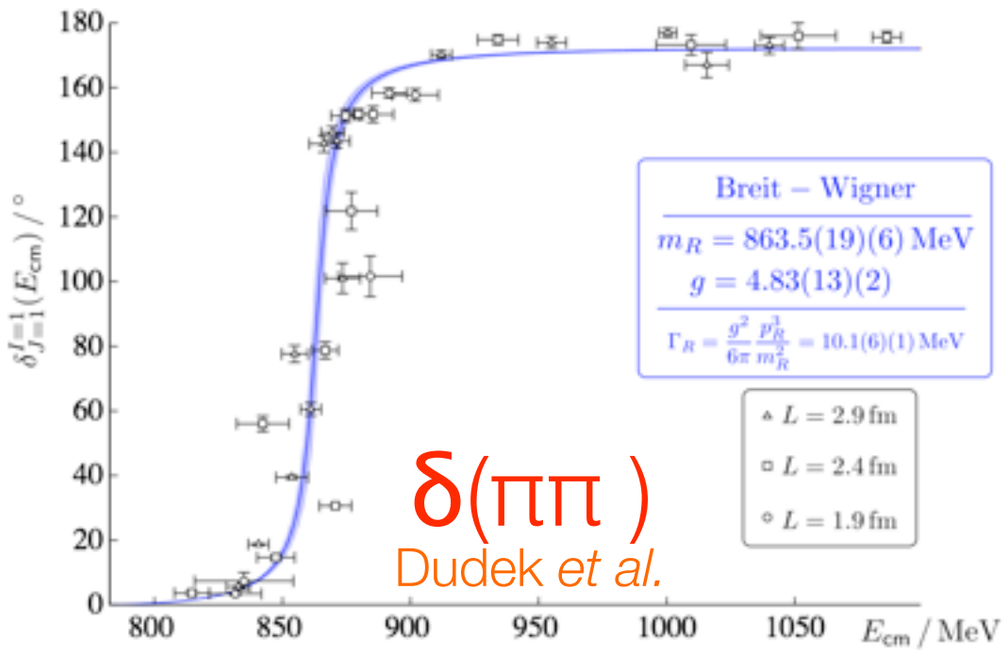
Spectrum



- Spectrum of mesons and baryons
  - exotics, molecules
  - coupled channels, etc





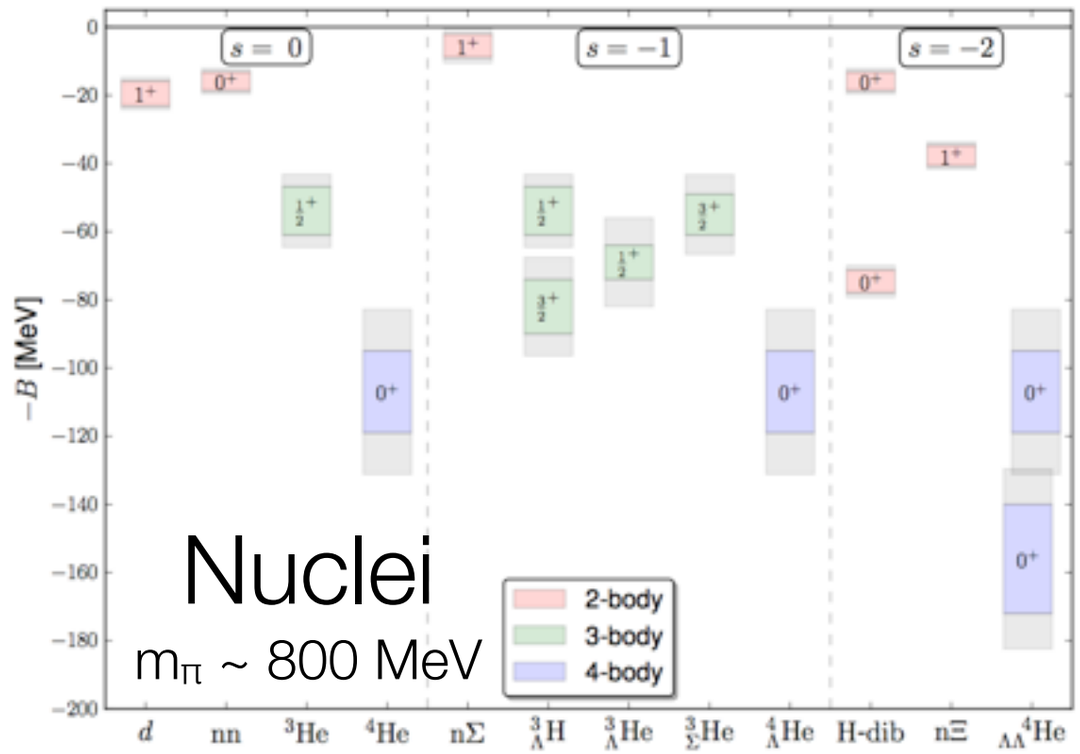


δ(ππ)

Dudek *et al.*

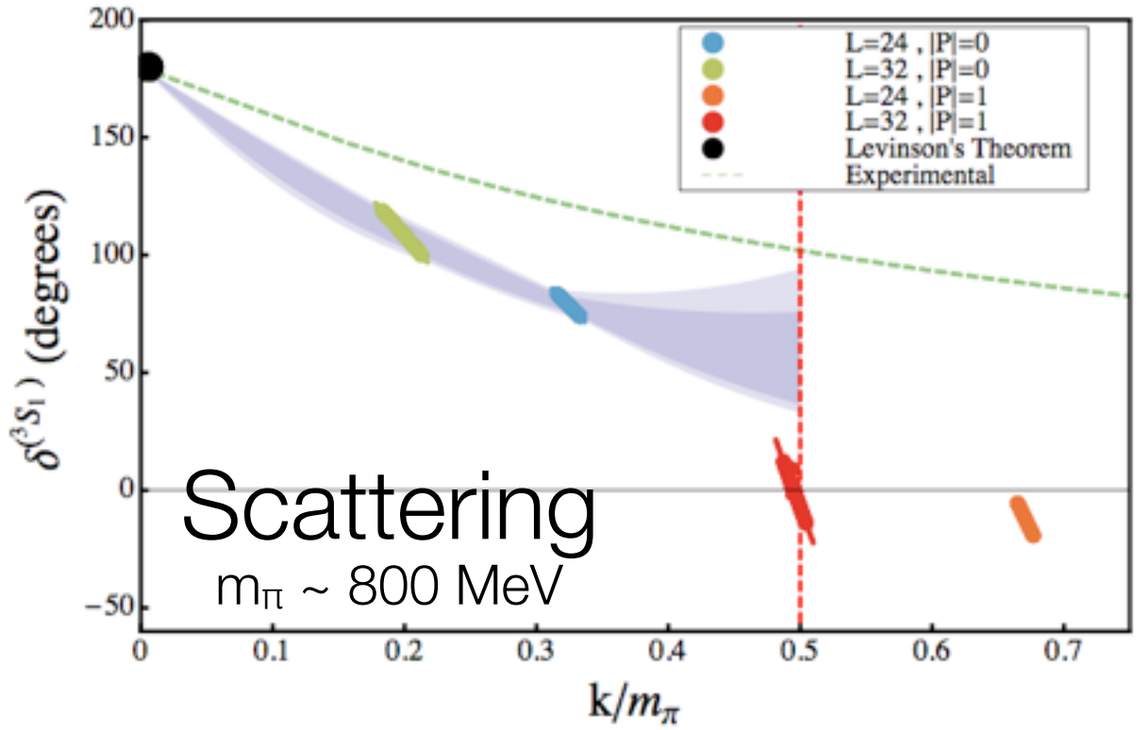
Lattice QCD needs to predict the exotic spectrum before or during the GlueX experiment

Hadronic Interactions



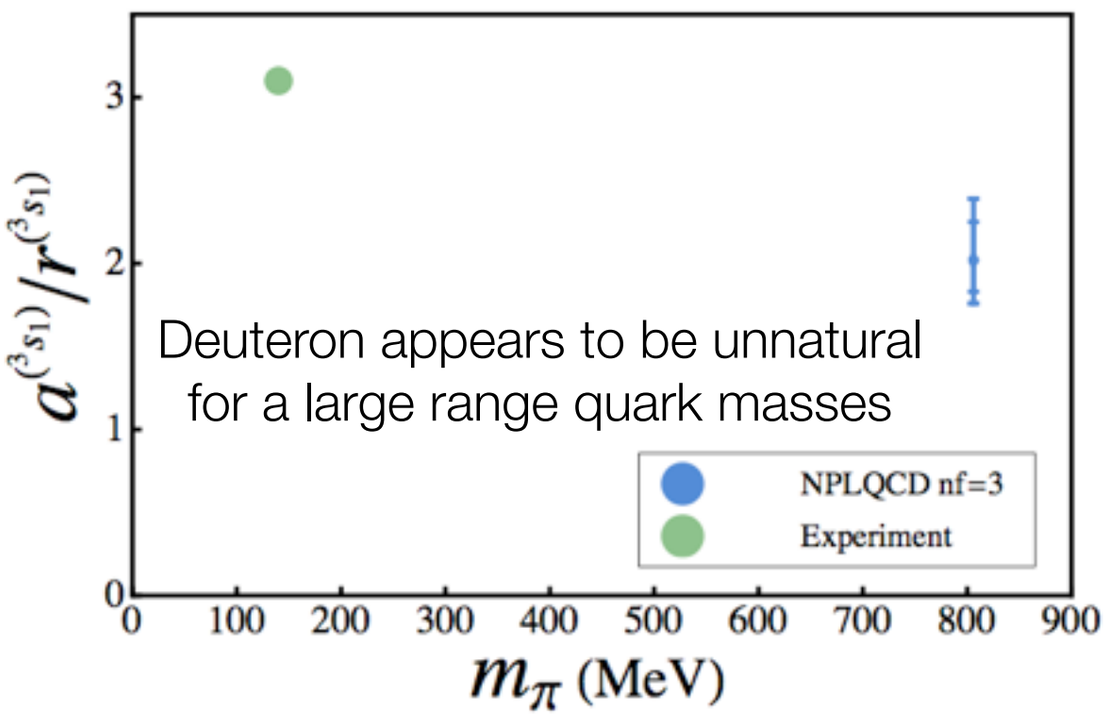
Nuclei

m_π ~ 800 MeV

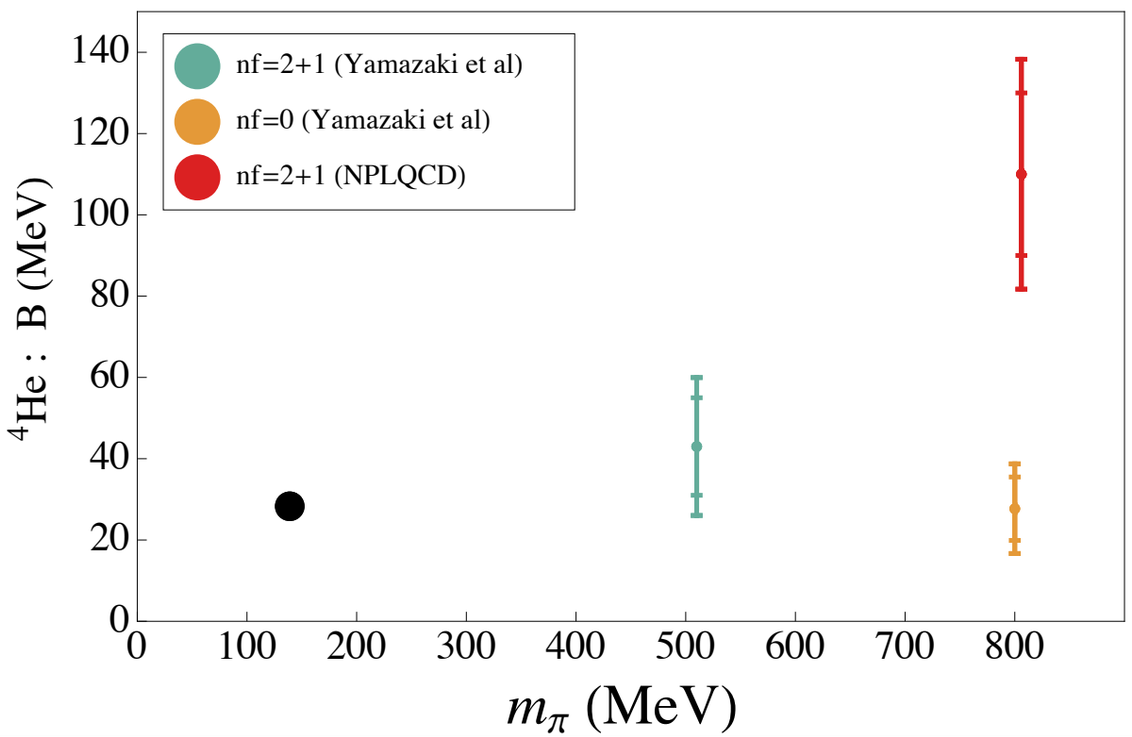


Scattering

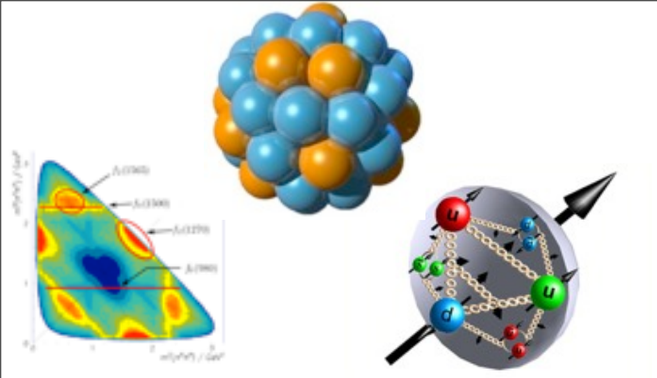
m_π ~ 800 MeV

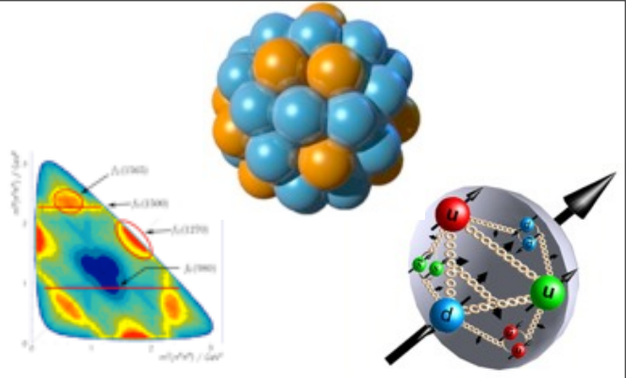


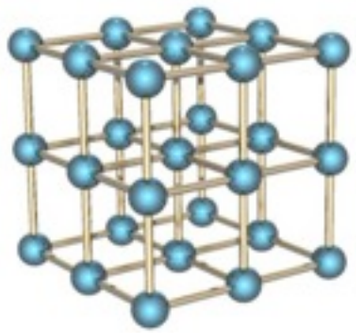
Deuteron appears to be unnatural for a large range quark masses



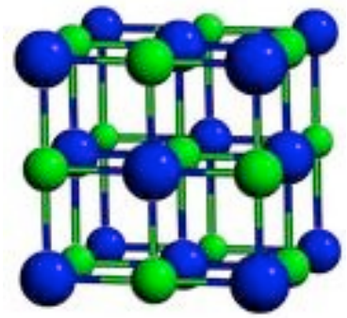
Present CNP Program



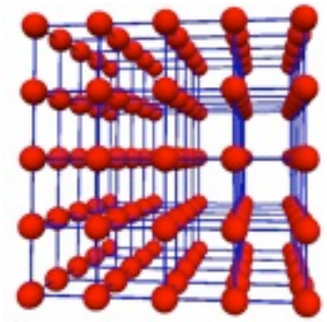




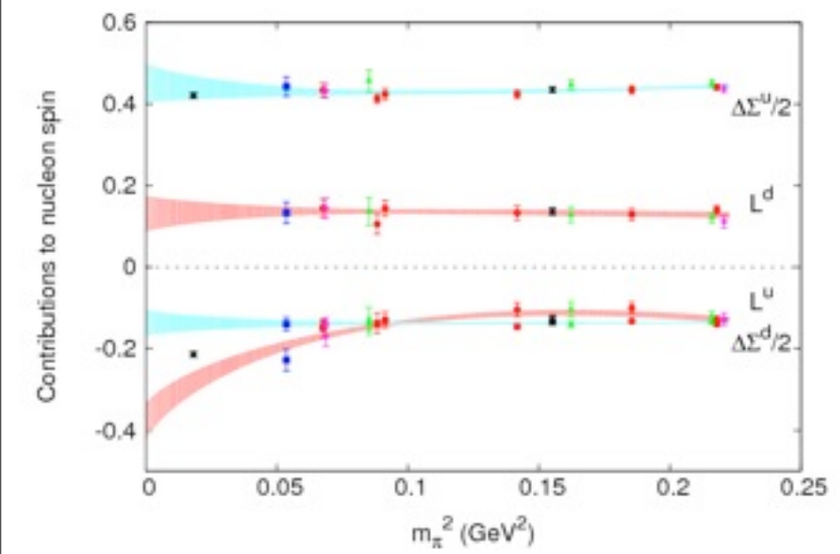
Isotropic clover, domain-wall, overlap, Staggered

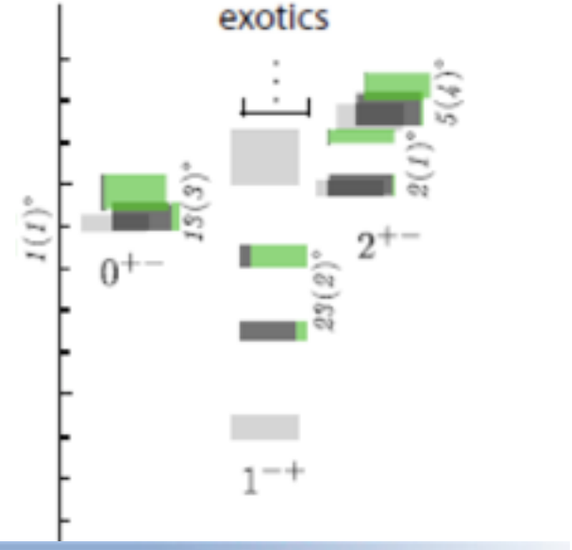


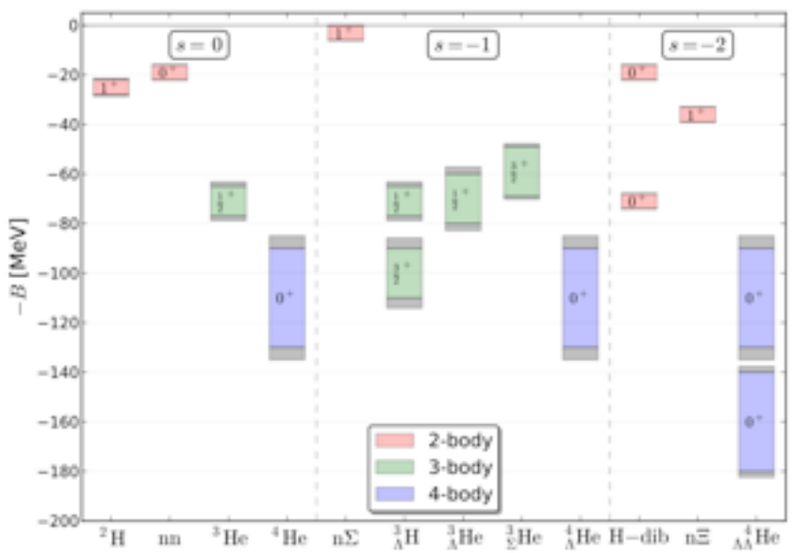
Anisotropic clover

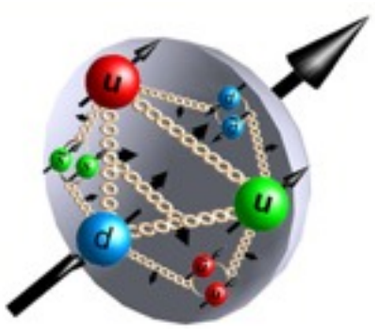


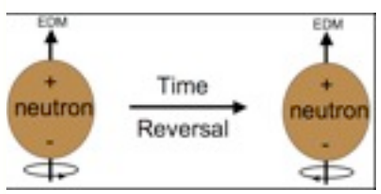
Isotropic clover

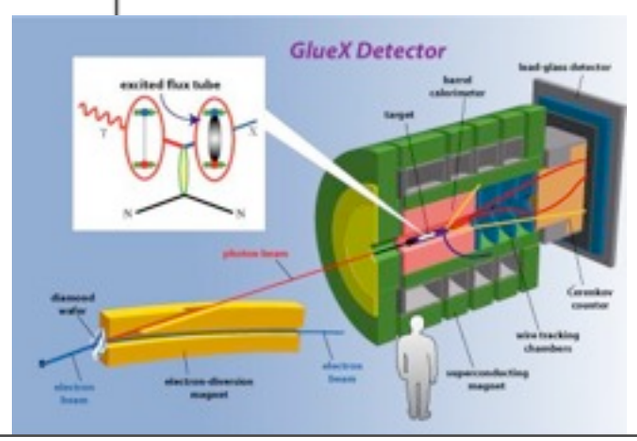


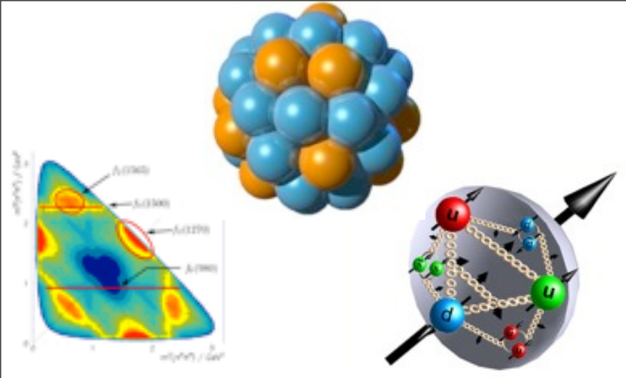




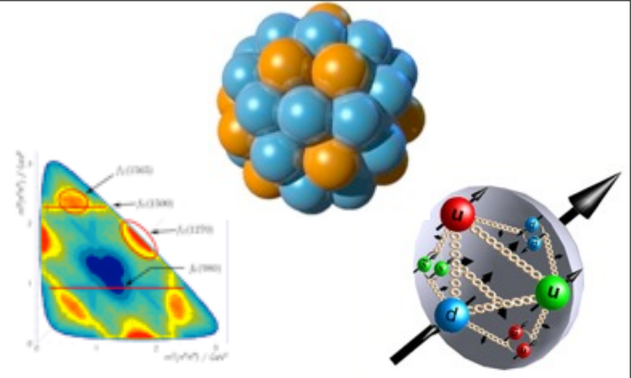


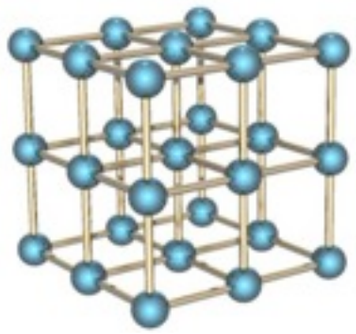




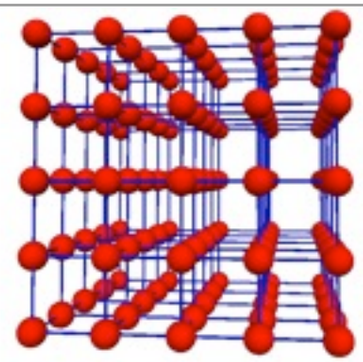


Future CNP Program
Physical Pion Mass



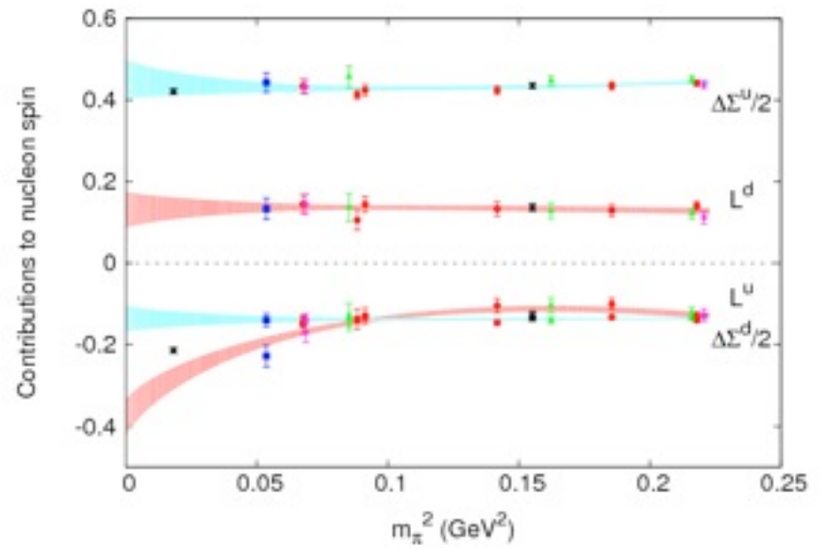


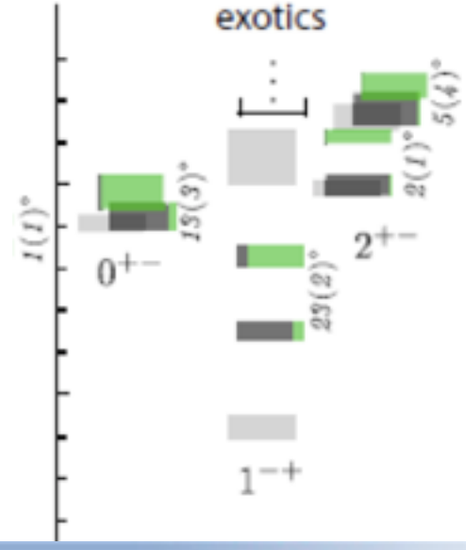
Domain-wall
Overlap

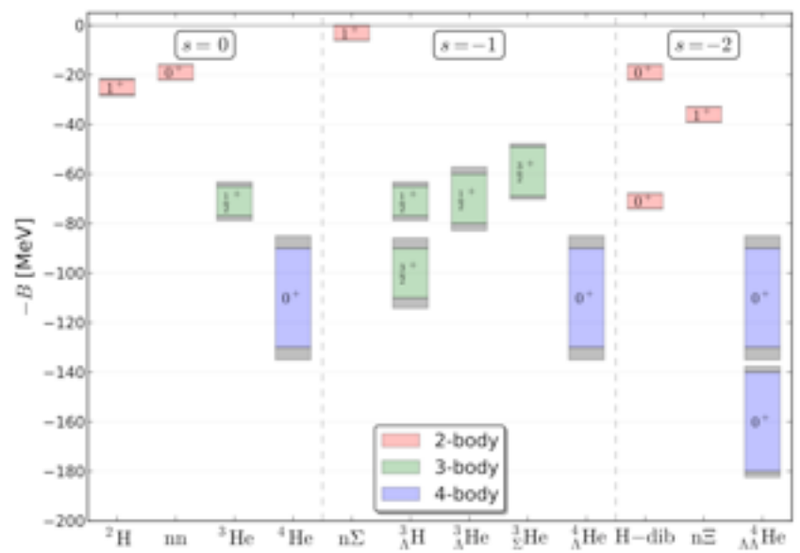


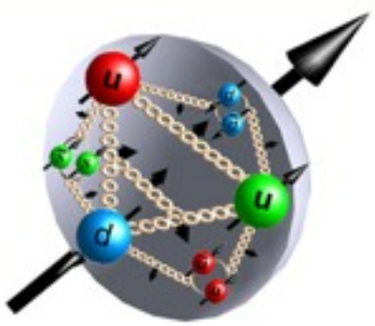
Isotropic clover : small enough lattice spacings

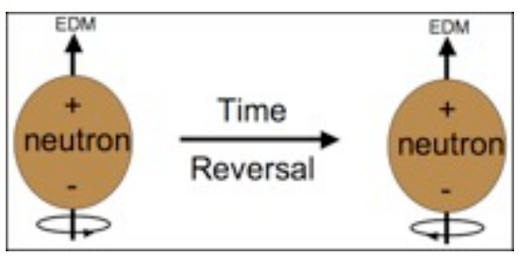
multi-neutron forces

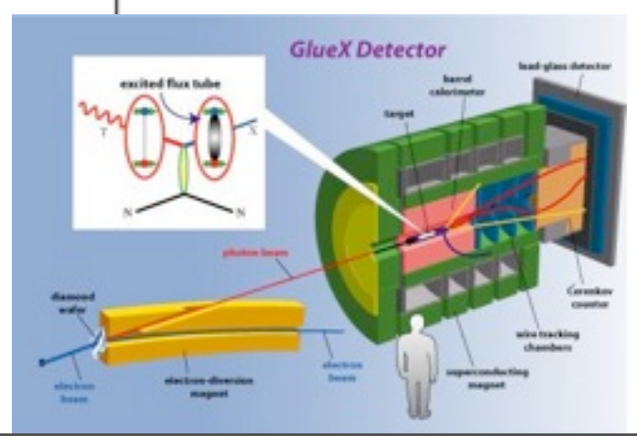








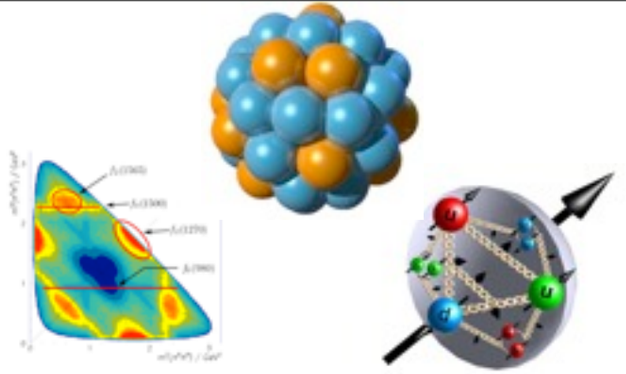




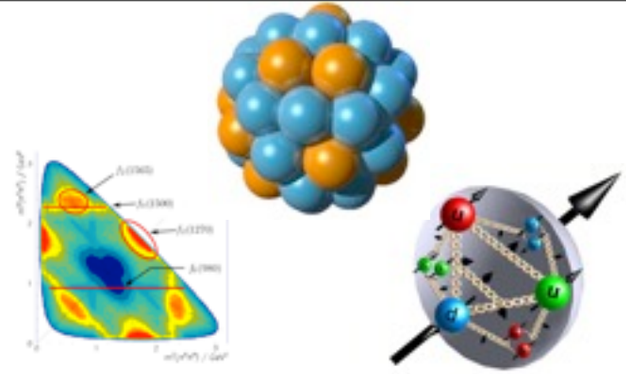
USQCD Proposed Production 2014-2019



$N_s^3 \times N_t$	Action	a fm	m_π MeV	$m_\pi L$	$m_\pi T$	Traj.	Configs. (TF-yrs)	Str-A (TF-yrs)	Str-B	HSp	HI
$64^3 \times 128$	W	0.076	250	6.1	12.3	5×10^3	8				
$64^3 \times 128$	W	0.09	200	5.8	11.7	5×10^3	9			167	27
$32^3 \times 512$	AW	0.12	200	3.8	17.6	1×10^4	44			41	
$48^3 \times 512$	AW	0.12	200	5.8	17.6	1×10^4	197			142	
$48^3 \times 192$	W	0.09	140	3.0	12.3	5×10^3	7	40			
$64^3 \times 192$	W	0.09	140	4.1	12.3	5×10^3	21	40			
$96^3 \times 64$	W	0.09	140	6.1	4.1	5×10^3	24	13			
$96^3 \times 96$	W	0.09	140	6.1	6.1	5×10^3	40	20			
$96^3 \times 192$	W	0.09	140	6.1	12.3	5×10^3	96	40	350*	334	288
$128^3 \times 192$	W	0.076	140	6.9	10.4	5×10^3	323	67		792	970
$48^3 \times 96$	DWF	0.110	140	3.9	7.8	5×10^3		28	360†		
$64^3 \times 128$	DWF	0.086	140	3.9	7.8	5×10^3		64	844†		

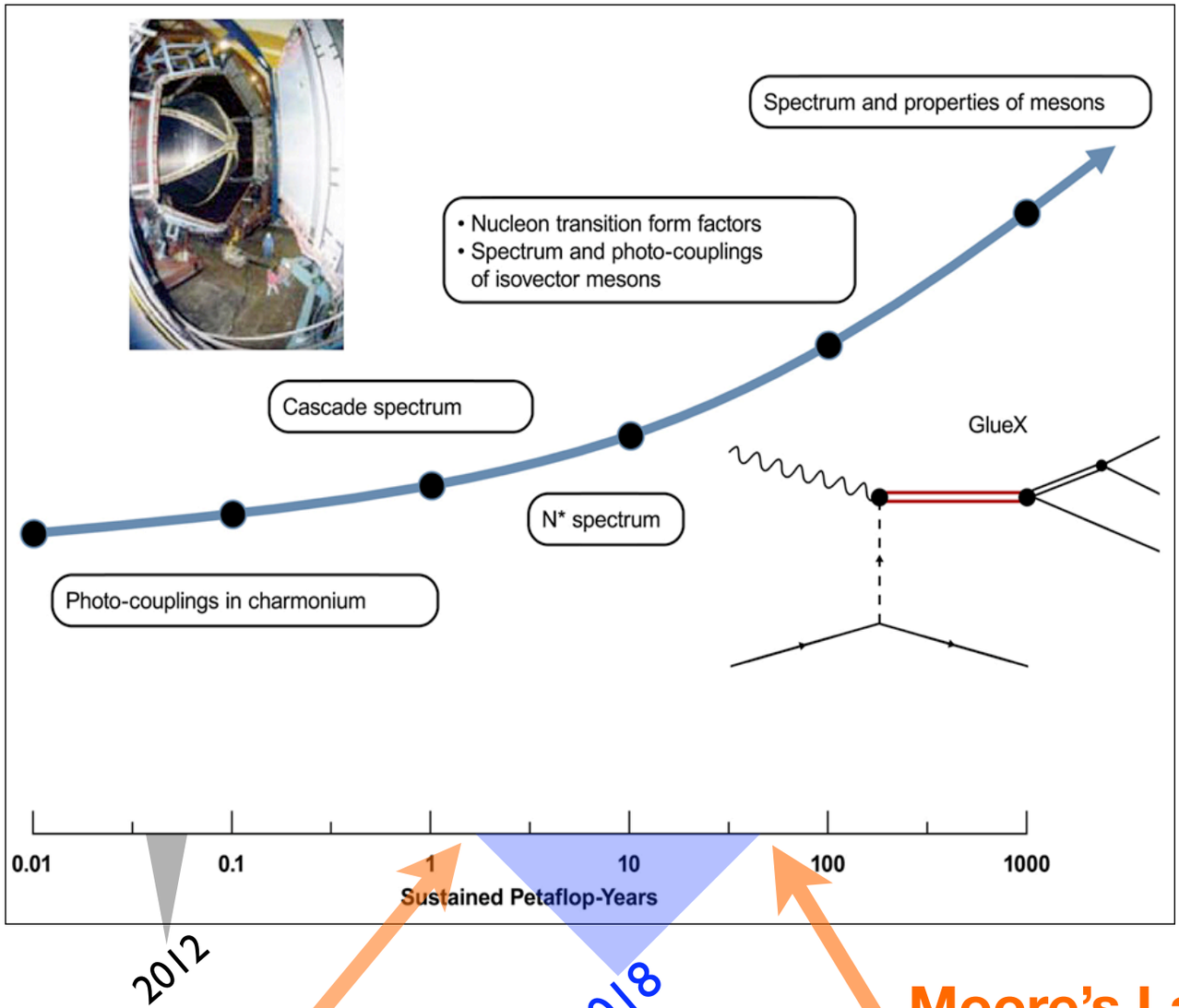


Compute Resources for Viability

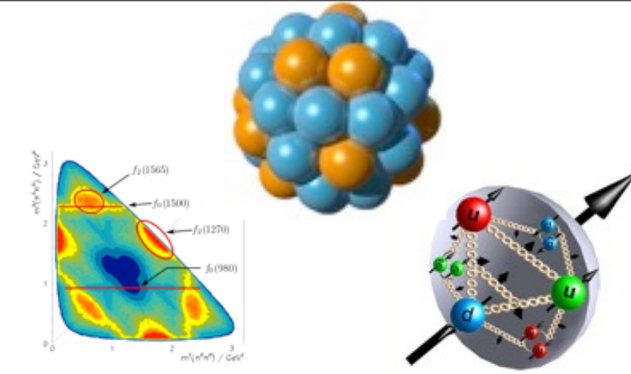


- Keeps the US competitive in many areas (with risk)
- Somewhat behind the experimental time table
- Maintain fraction of Leadership-Class resources (~15%)

e.g.
Hadronic
Spectrosopy



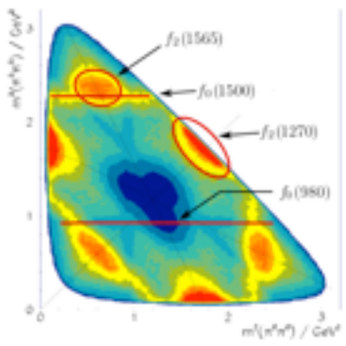
Cold Nuclear Physics Summary

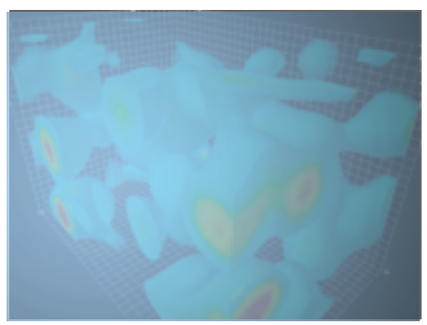


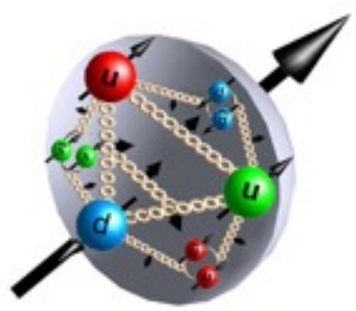
- Transformational period for Cold Nuclear Physics
  - ORNL could play a major role in that transformation

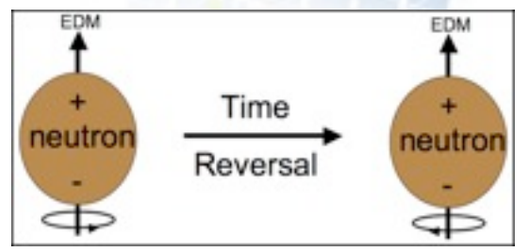
- Well-defined plan for successful program in CNP
  - spectrum, structure and interactions
    - coherent program

- Nuclear Physics at the physical pion mass
  - fully quantified uncertainties
  - direct input into existing nuclear efforts
    - both theory and experiment









The End, or is it the Beginning