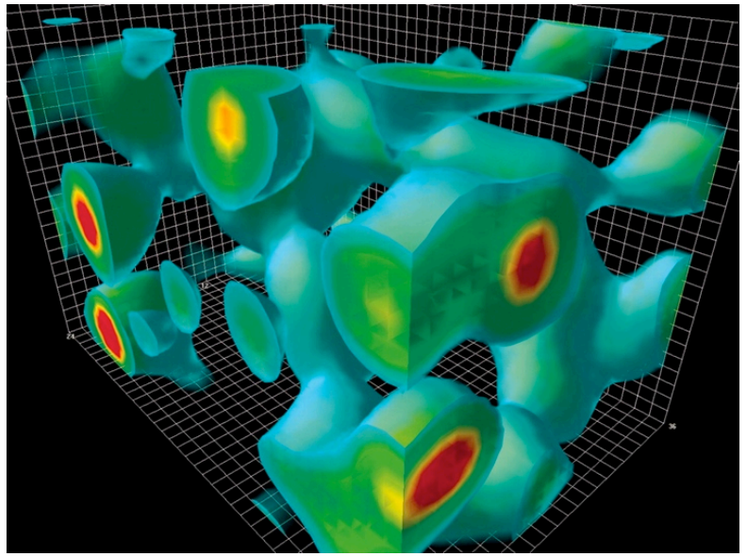
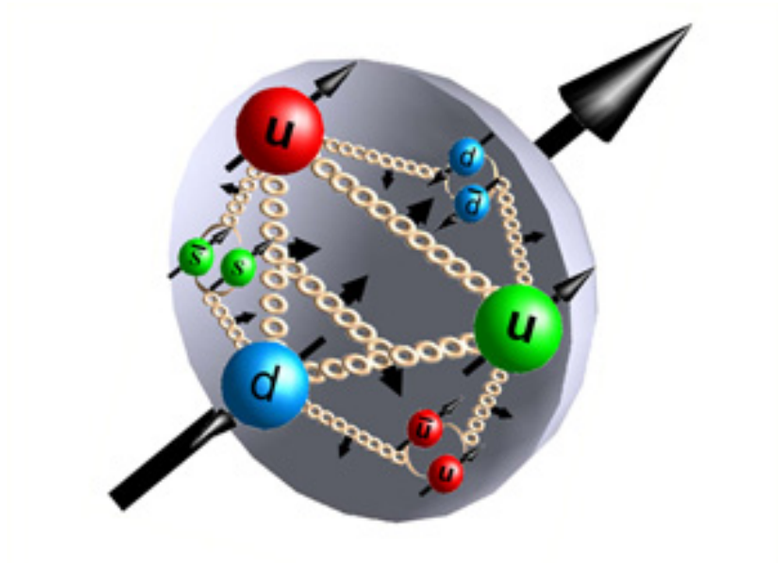
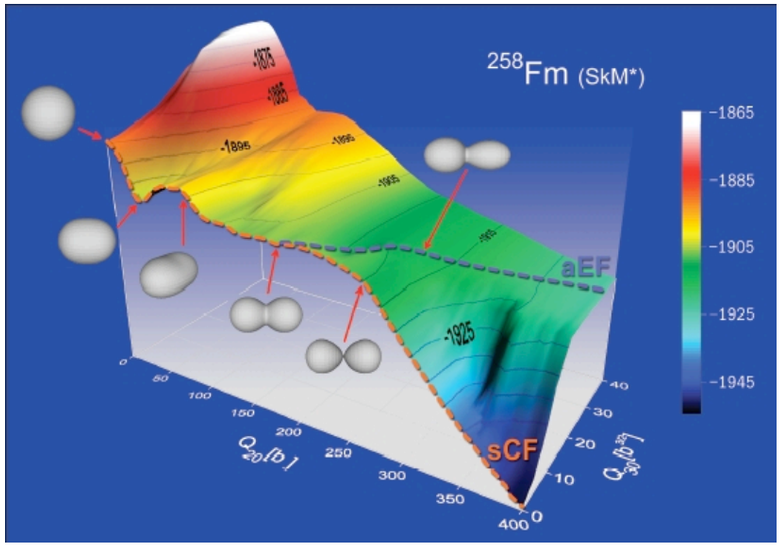






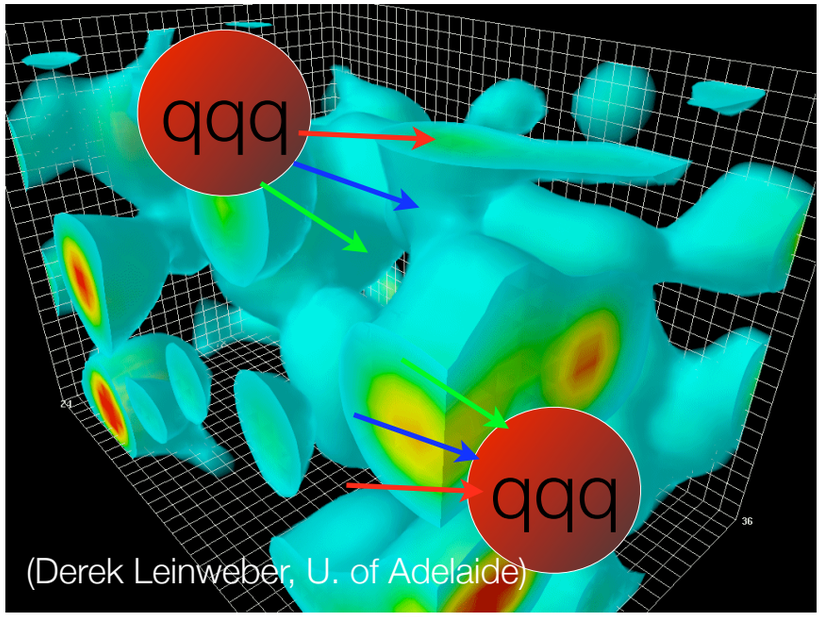
Hadronic Interactions with Lattice QCD

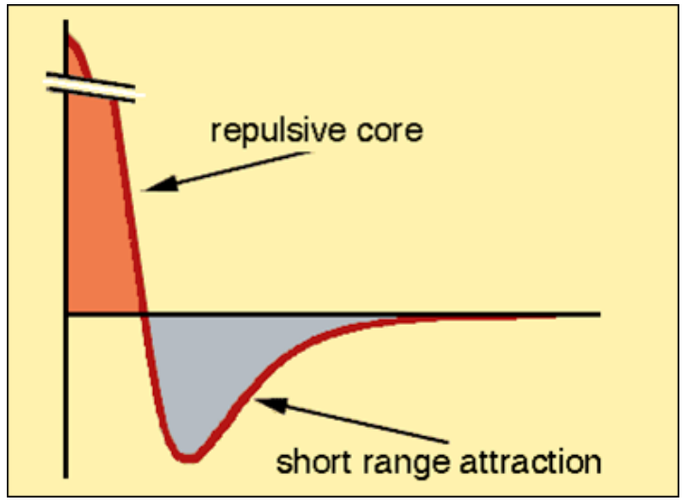
Martin J. Savage (Univ. of Washington)

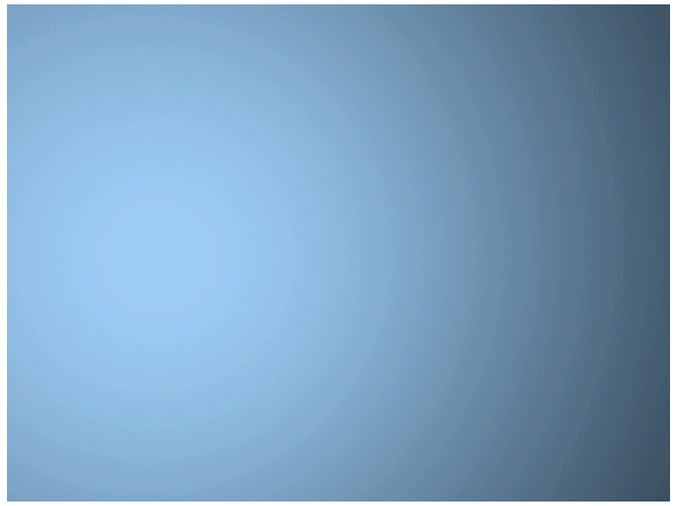
MENU 2010

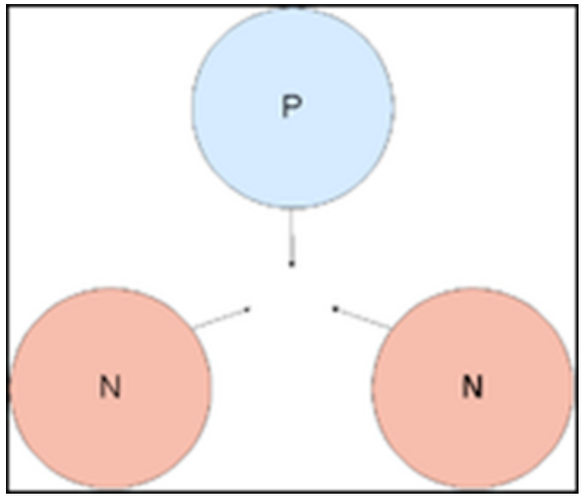
May 31-June 4, 2010
College of William and Mary
Williamsburg, Virginia, USA

Nuclear Forces and Multi-Hadron Systems



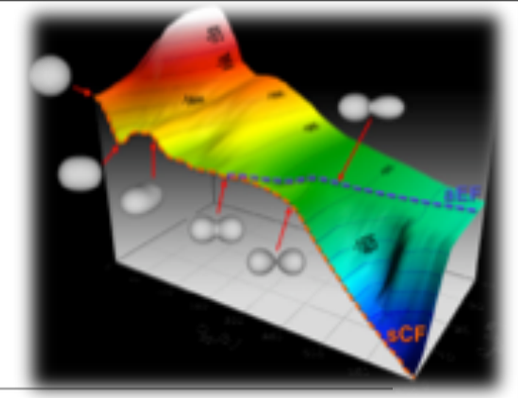


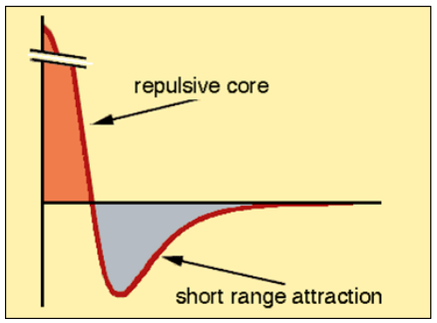


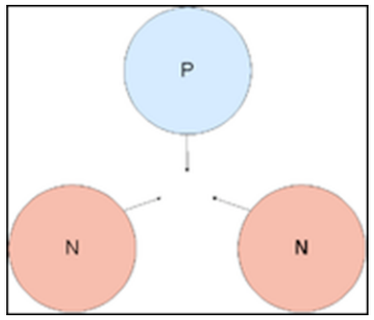


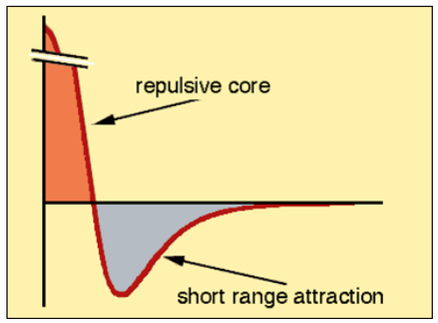
Numerical Calculations with Quantifiable Uncertainties

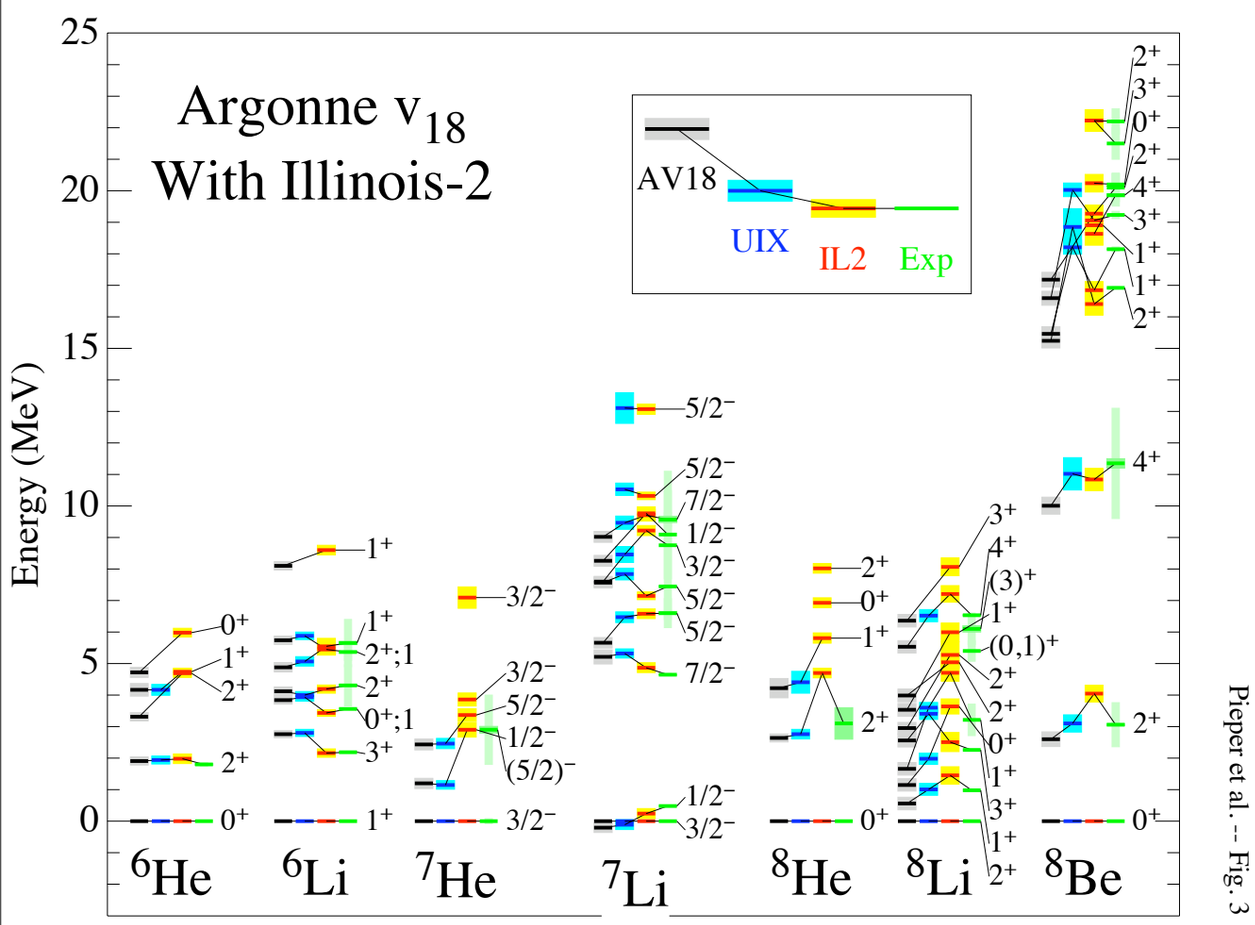
Light and Medium Nuclei, Fusion e.g. GFMC and NCSM











Proton-Dripping Fluorine-14

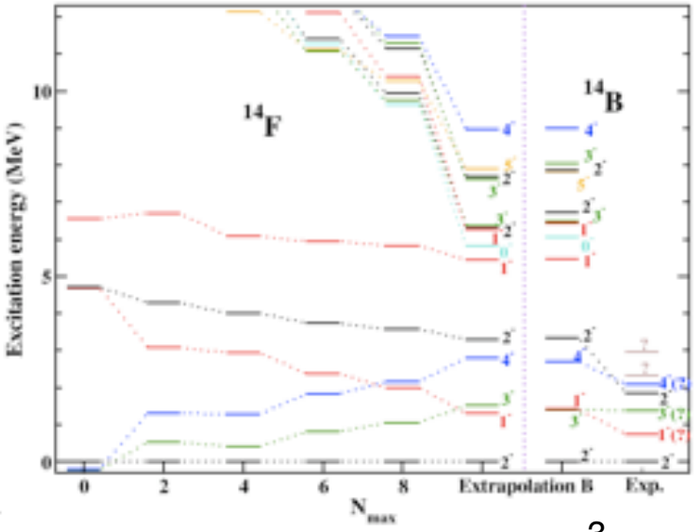
First principles quantum solution for yet-to-be-measured unstable nucleus ^{14}F

- Apply *ab initio* microscopic nuclear theory's predictive power to major test case
- Robust predictions important for improved energy sources
- Providing important guidance for DOE-supported experiments
- Comparison with new experiment will improve theory of strong interactions
- Dimension of matrix solved for 14 lowest states ~ 2×10^9
- Solution takes ~ 2.5 hours on 30,000 cores (Cray XT4 Jaguar at ORNL)

Predictions:

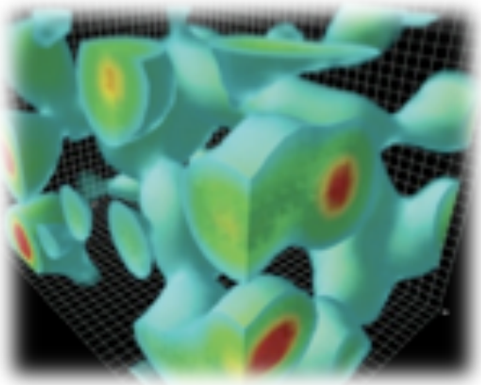
Binding energy: 72 ± 4 MeV indicating that Fluorine-14 will emit (drip) one proton to produce more stable Oxygen-13.

Predicted spectrum (Extrapolation B) for Fluorine-14 which is nearly identical with predicted spectrum of its "mirror" nucleus Boron-14. Experimental data exist only for Boron-14 (far right column).

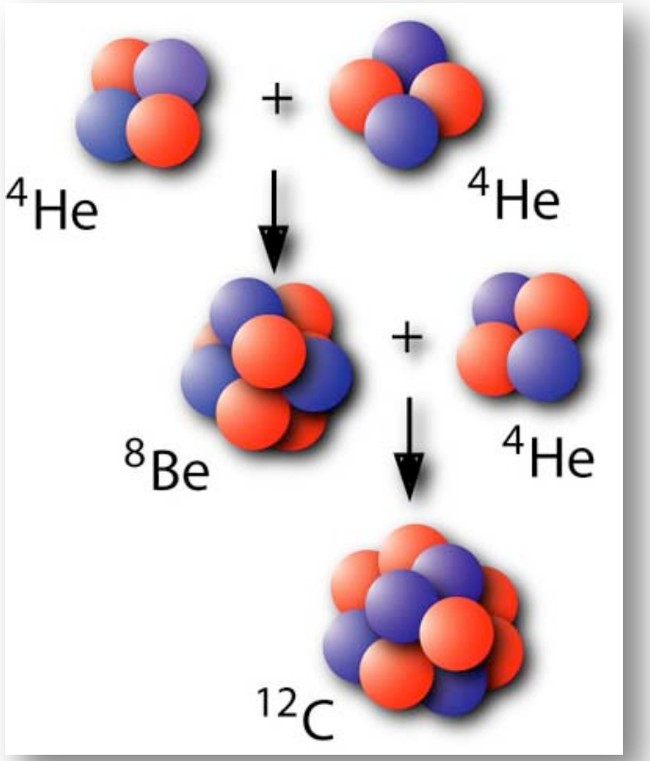


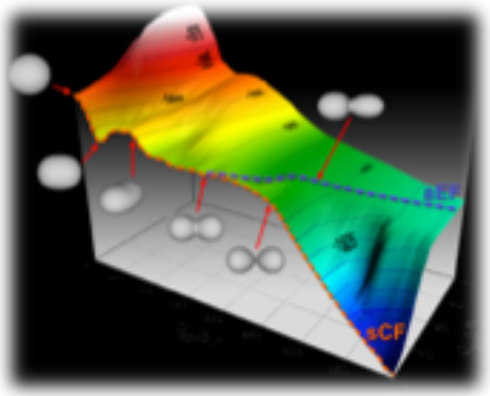
P. Maris, A. M. Shirokov and J. P. Vary, PRC, Rapid Comm., accepted, nucl-th 0911.2281

Fundamental Question(s) about our Universe



Cold QCD and Nuclear Forces





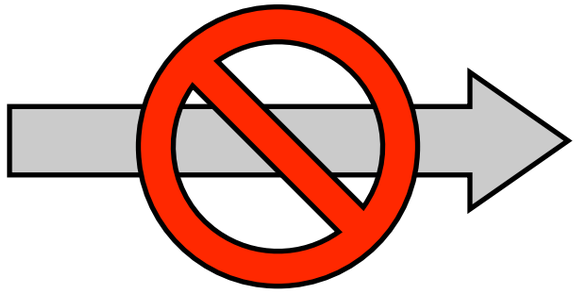
Nuclear Structure and Reactions

- Nuclear Physics is Fine-Tuned
  - *Why ??*
  - *How much ??*
  - *Can other quark masses produce sufficient carbon ?*

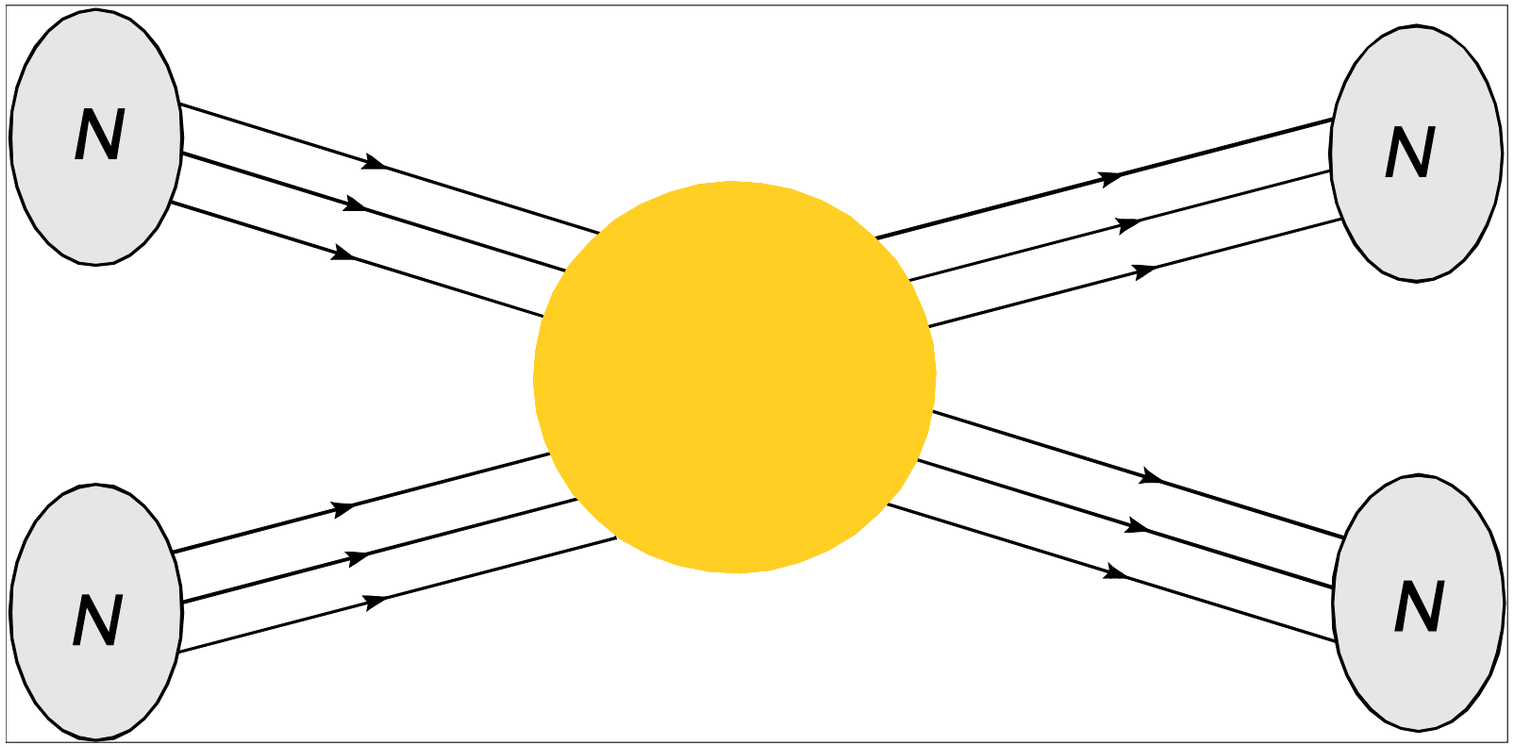
- Lattice QCD Calculations will provide answers

Maiani-Testa Theorem
Implications for Nuclear Physics !

Away from Kinematic Thresholds



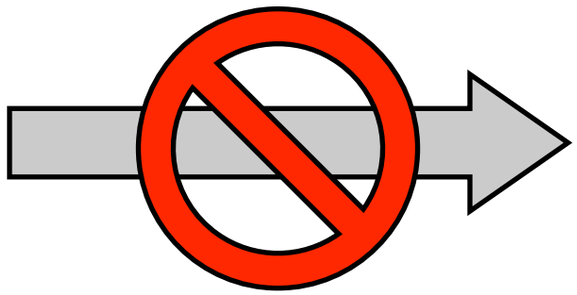
Maiani-Testa Theorem
Implications for Nuclear Physics !



δ (s) ?

Away from Kinematic Thresholds

G_{NN} (s)^{Euclidean}



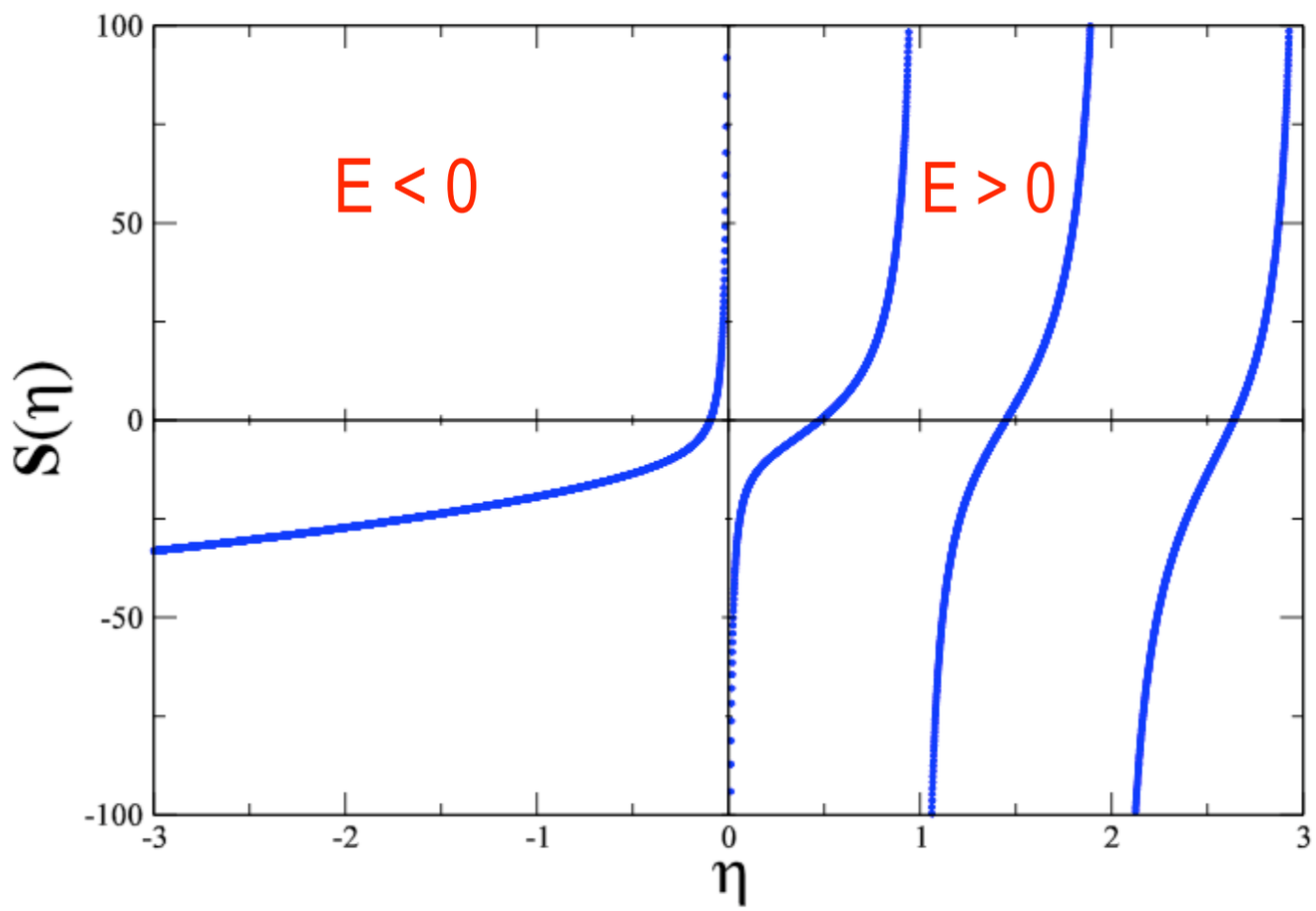
G_{NN} (s)^{Minkowski}

Energy Eigenvalues and the Luscher Relation

Below Inelastic Thresholds :

Measure on lattice

$$\delta E = 2\sqrt{p^2 + m^2} - 2m$$



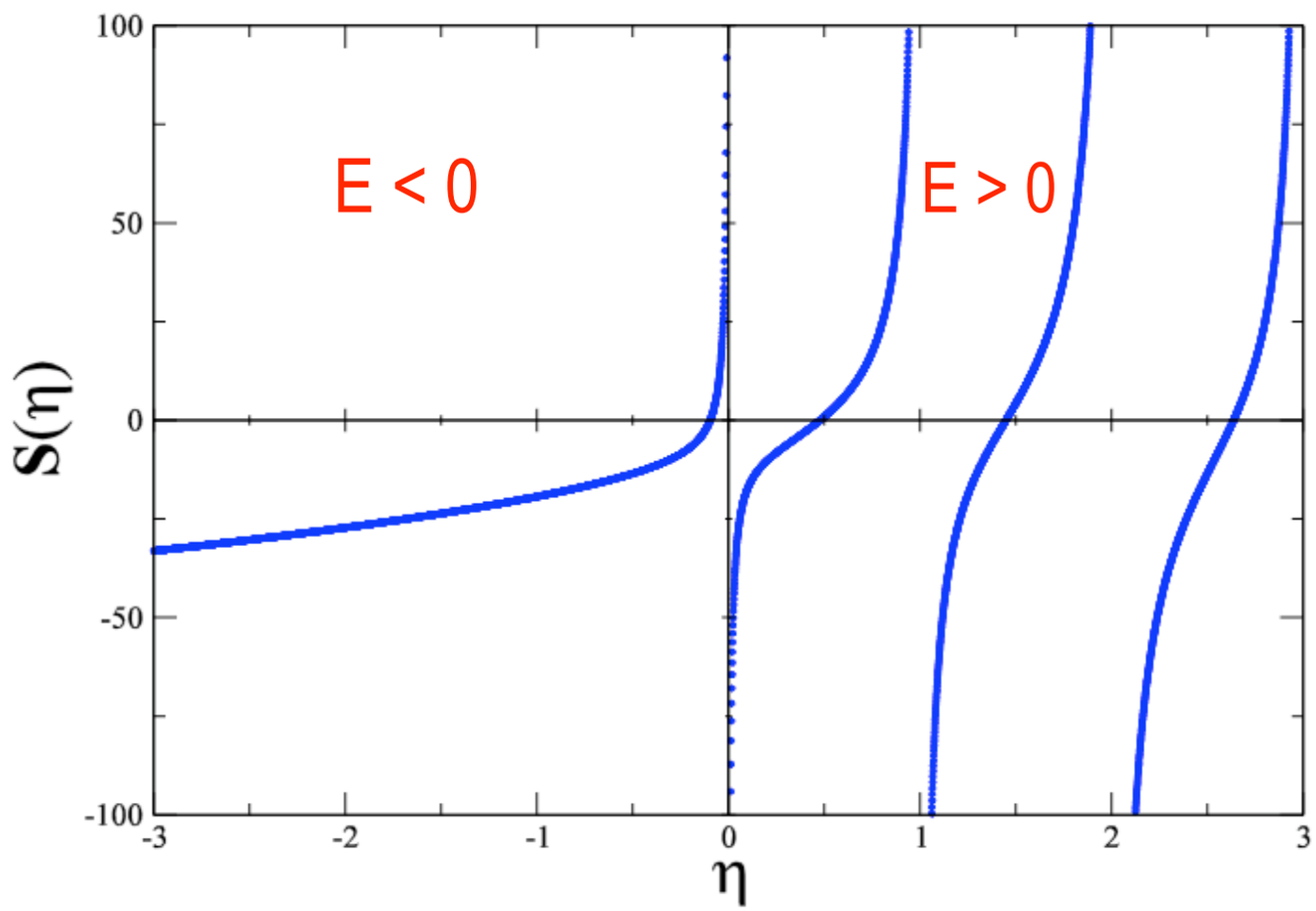
Energy Eigenvalues and the Luscher Relation

Below Inelastic Thresholds :

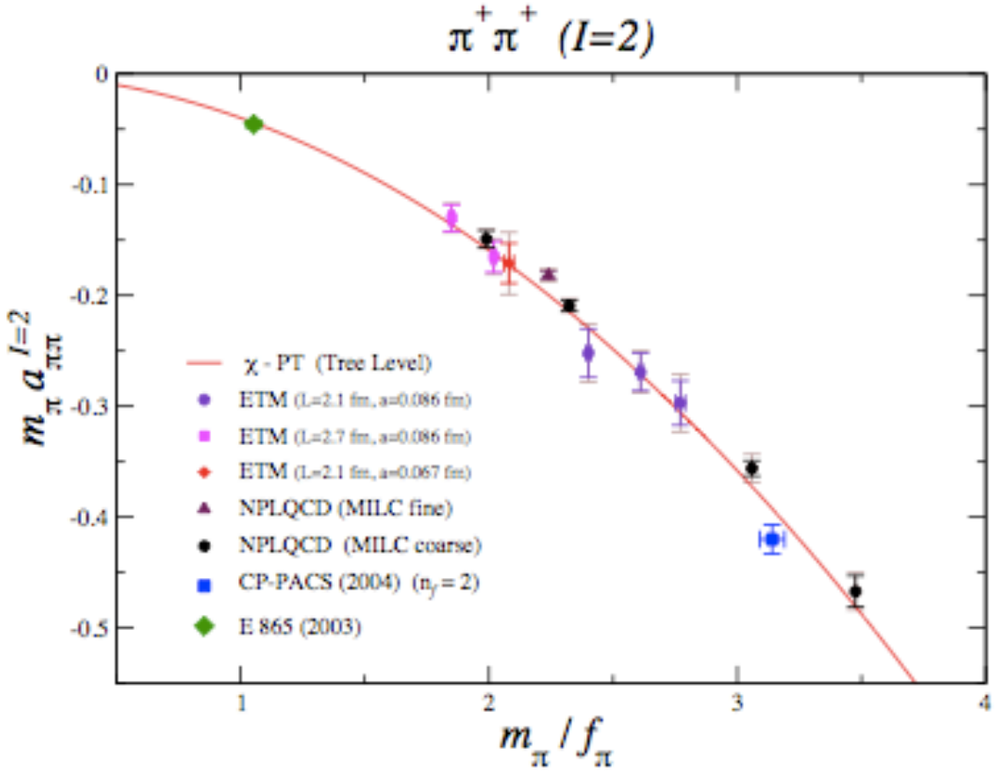
Measure on lattice

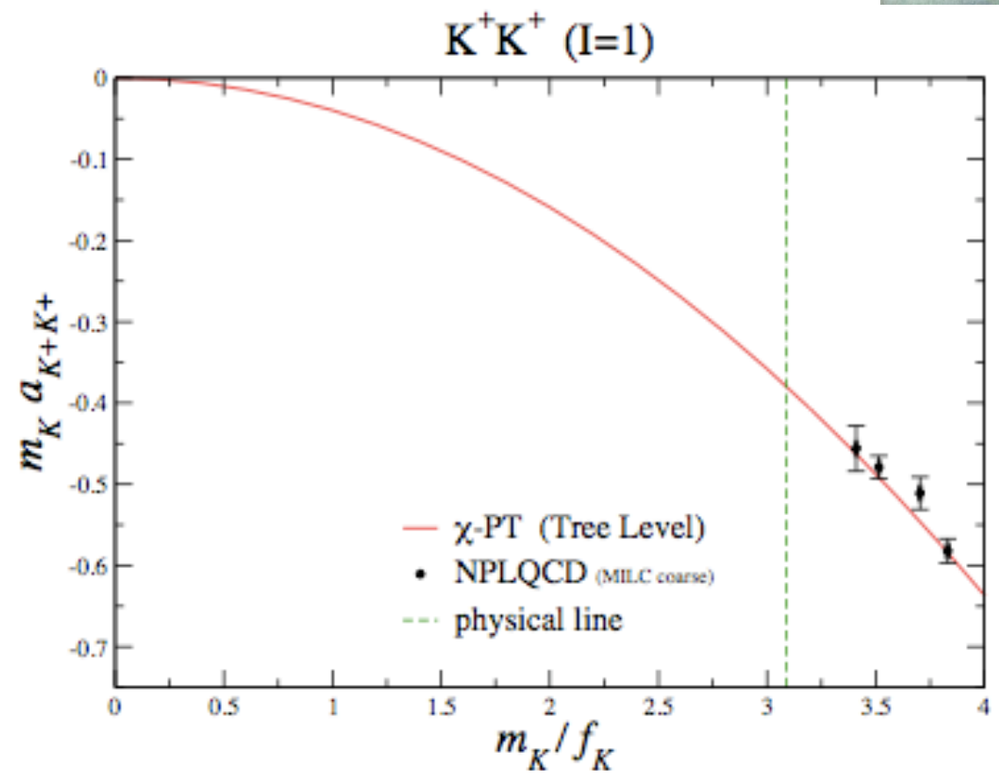
$$\delta E = 2\sqrt{p^2 + m^2} - 2m$$

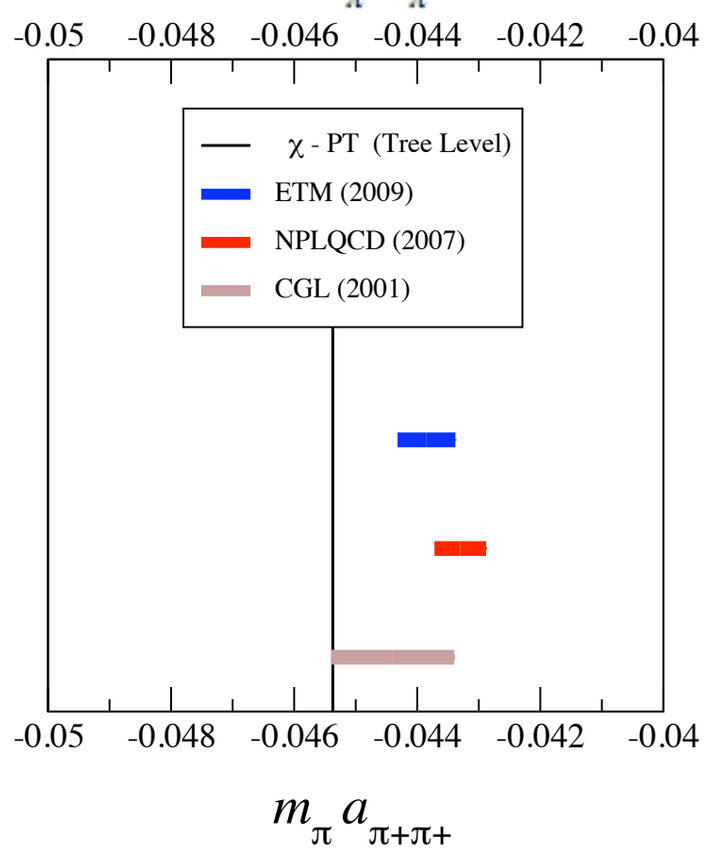
$$p \cot \delta(p) = \frac{1}{\pi L} \mathbf{S}\left(\left(\frac{Lp}{2\pi} \right)^2 \right)$$

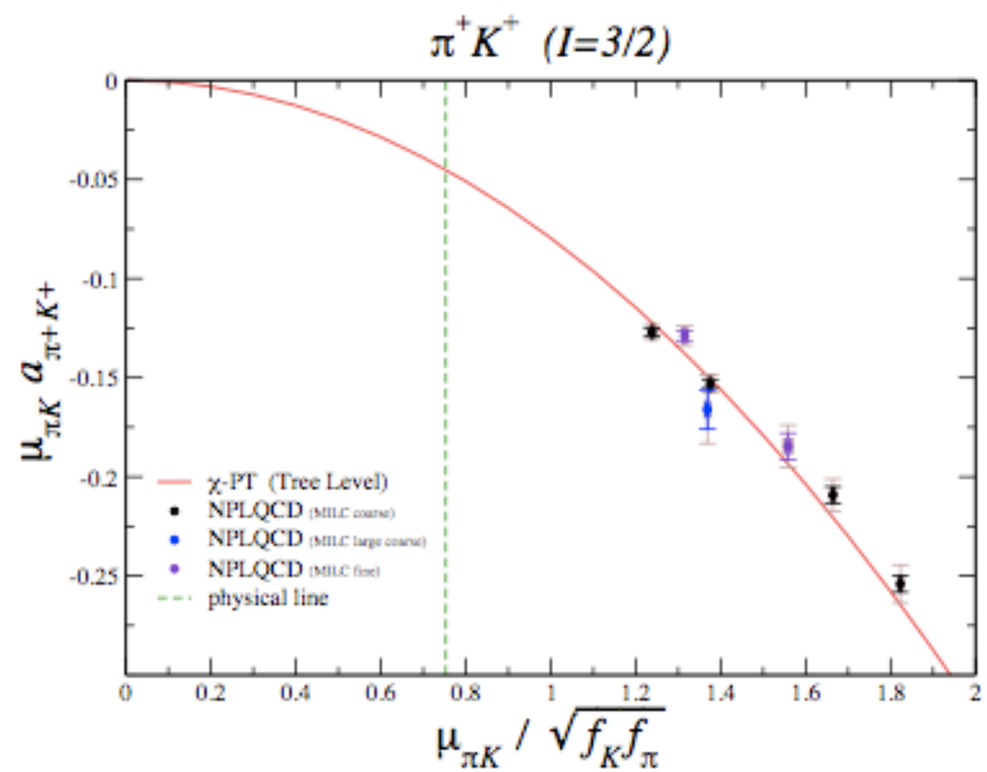


Meson-Meson Scattering

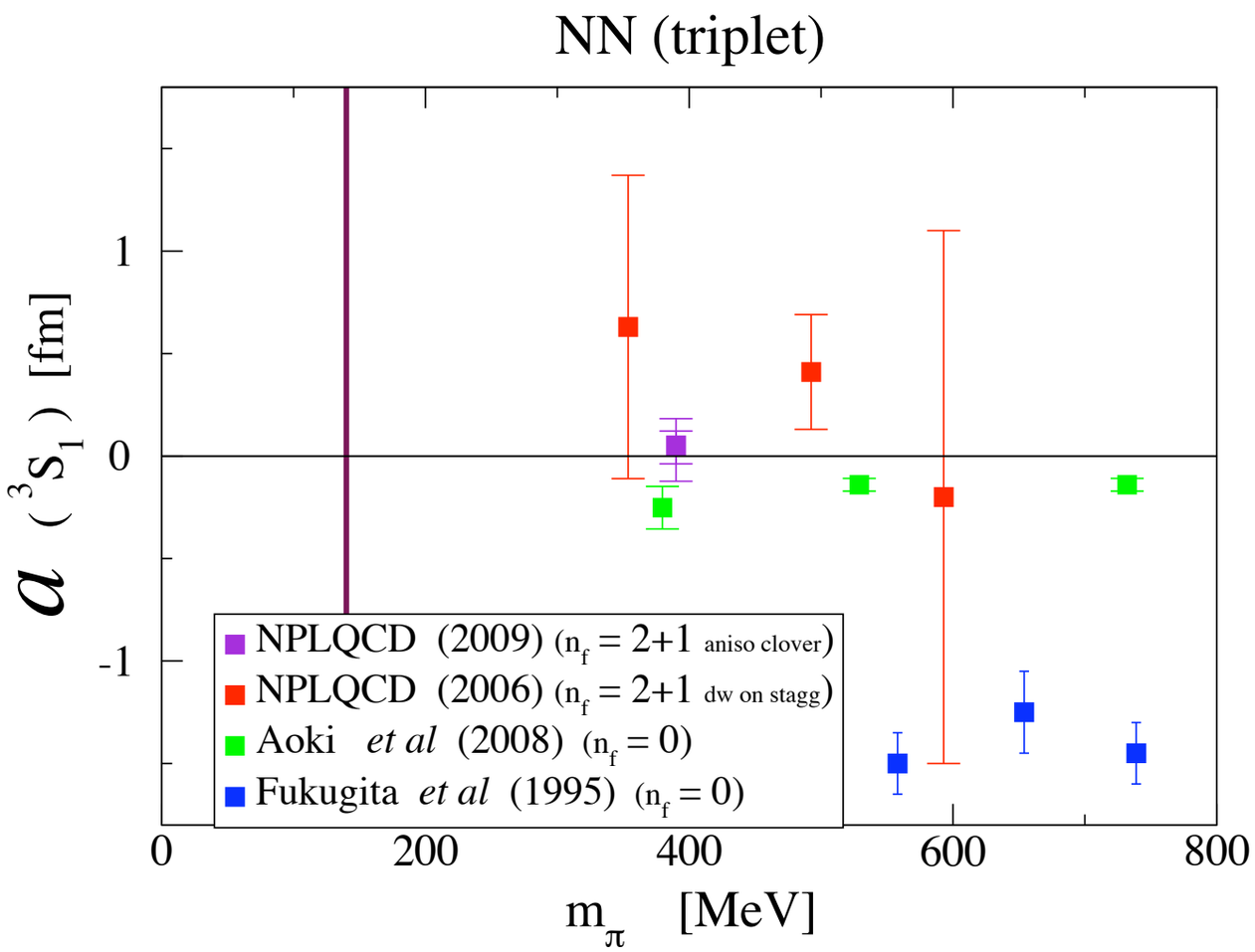


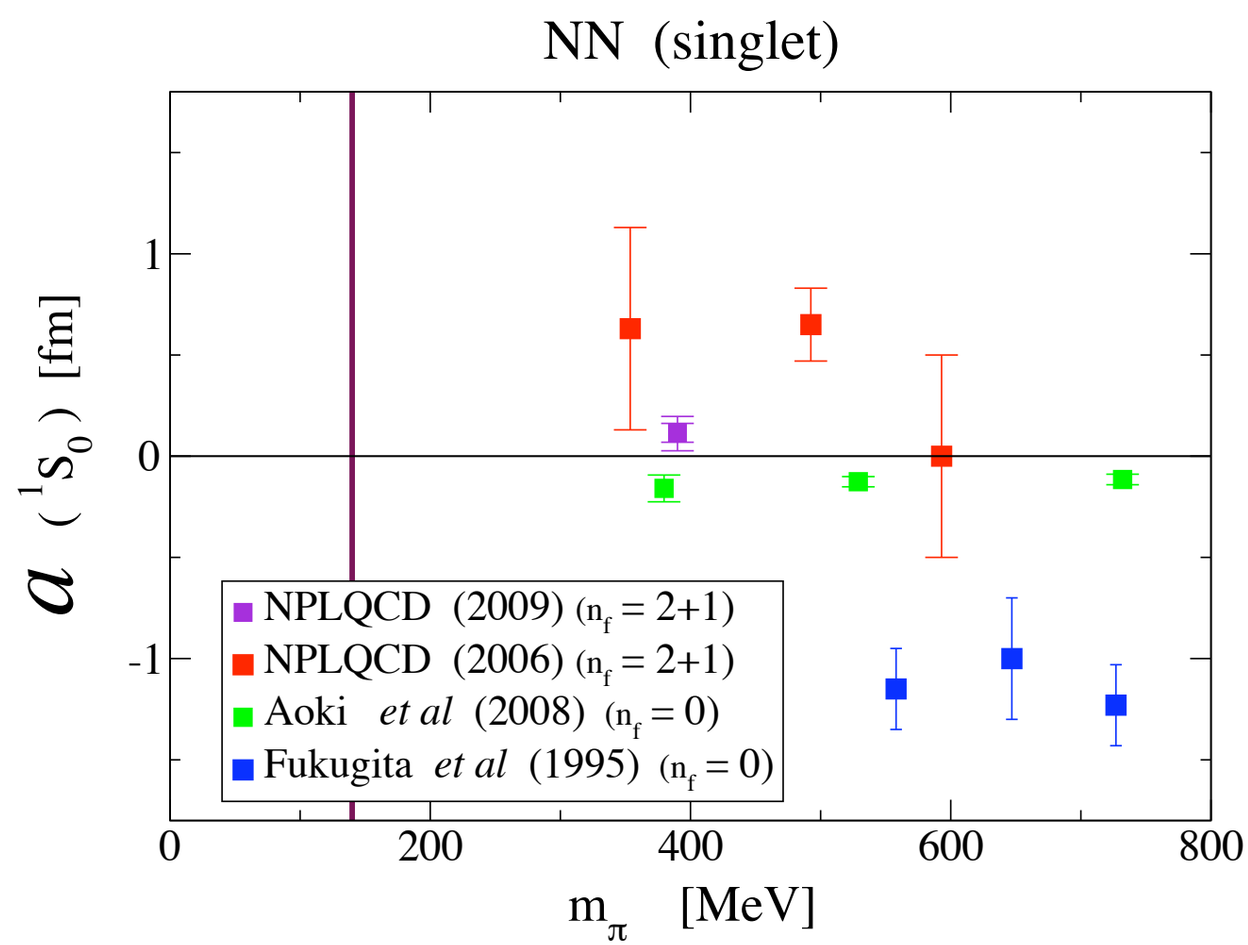






Nucleon-Nucleon Scattering

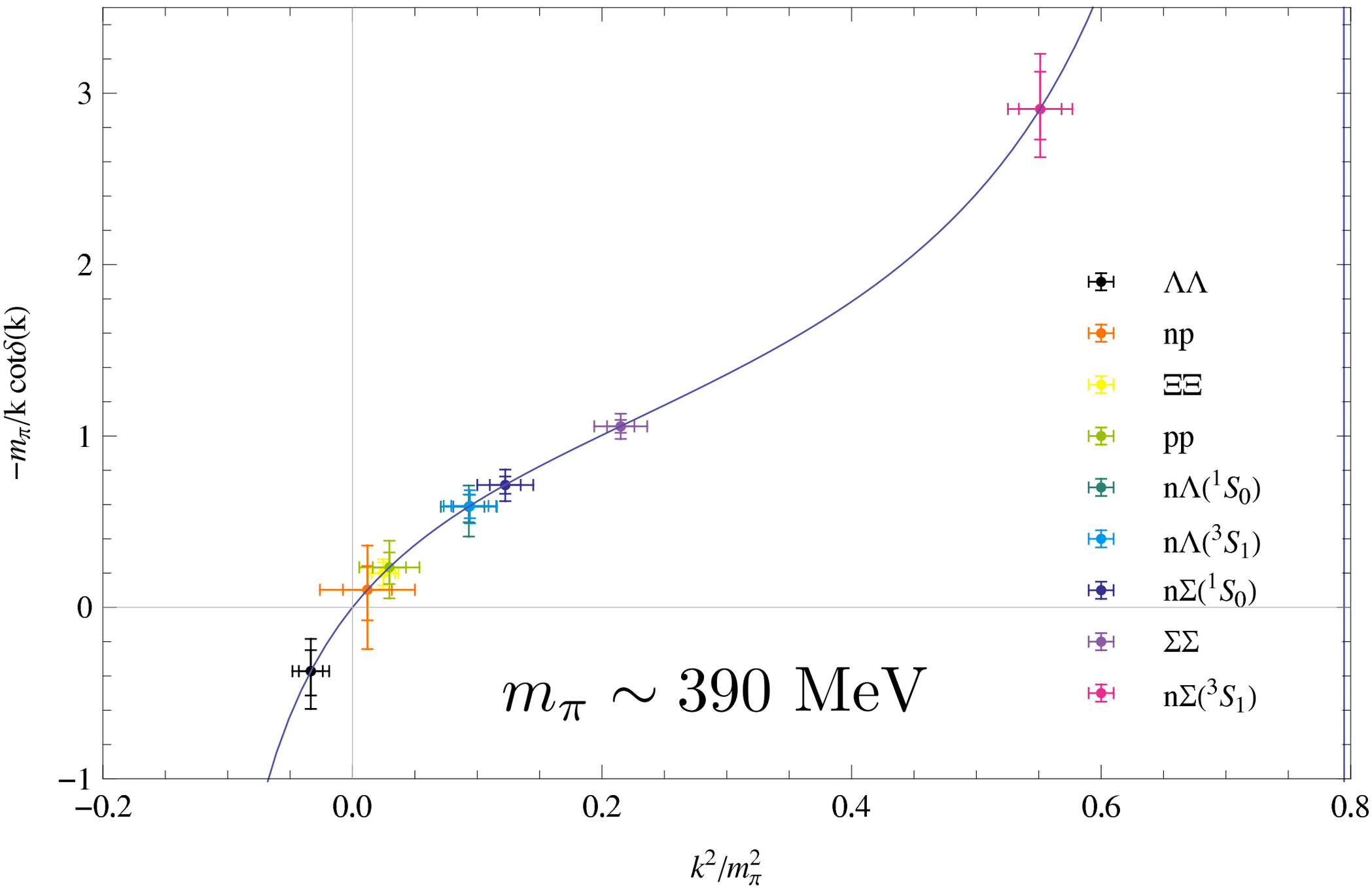




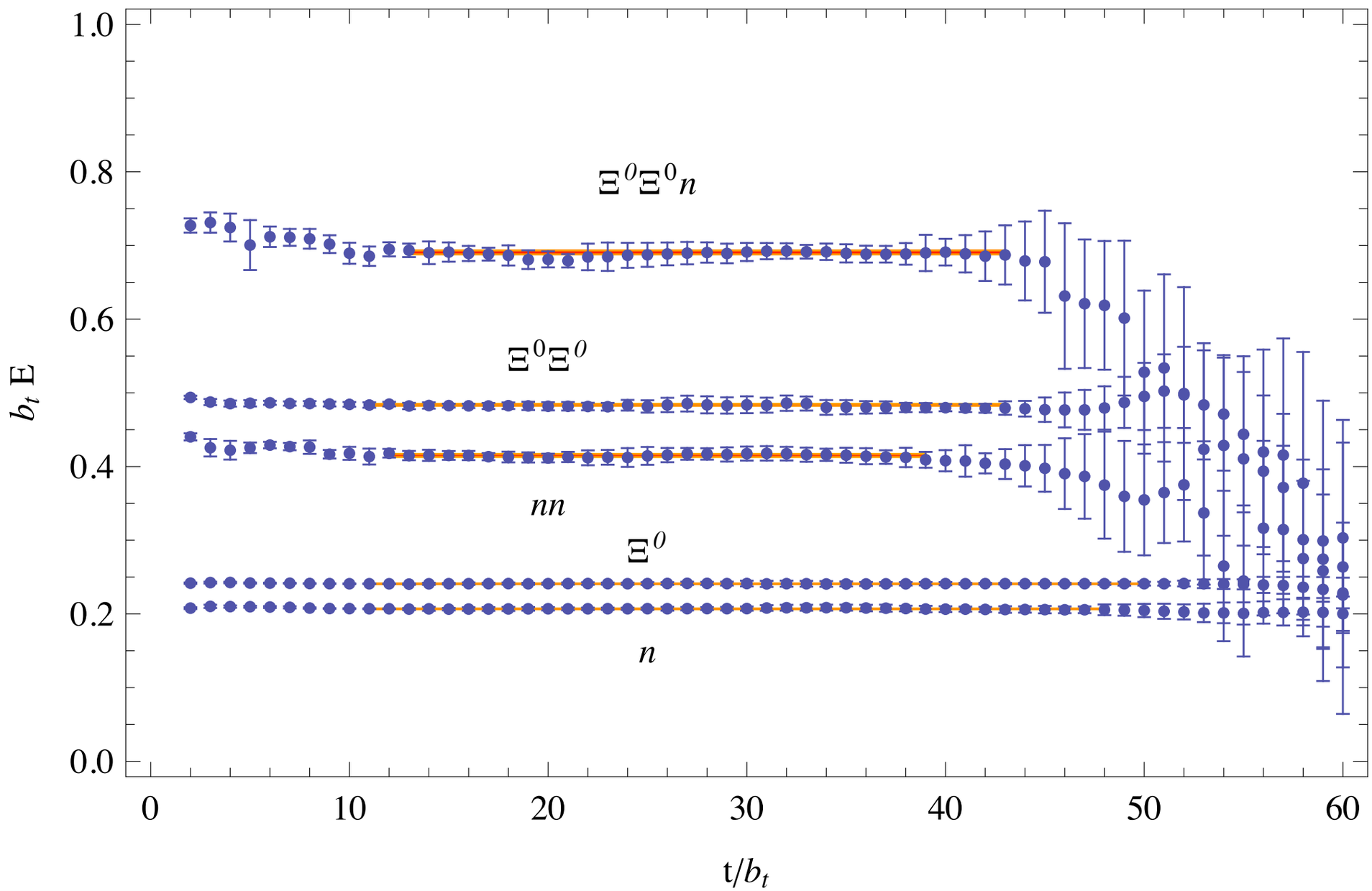
$^3S_1$-$^3D_1$: pn , deuteron

$^1S_0$: pp , pn , nn

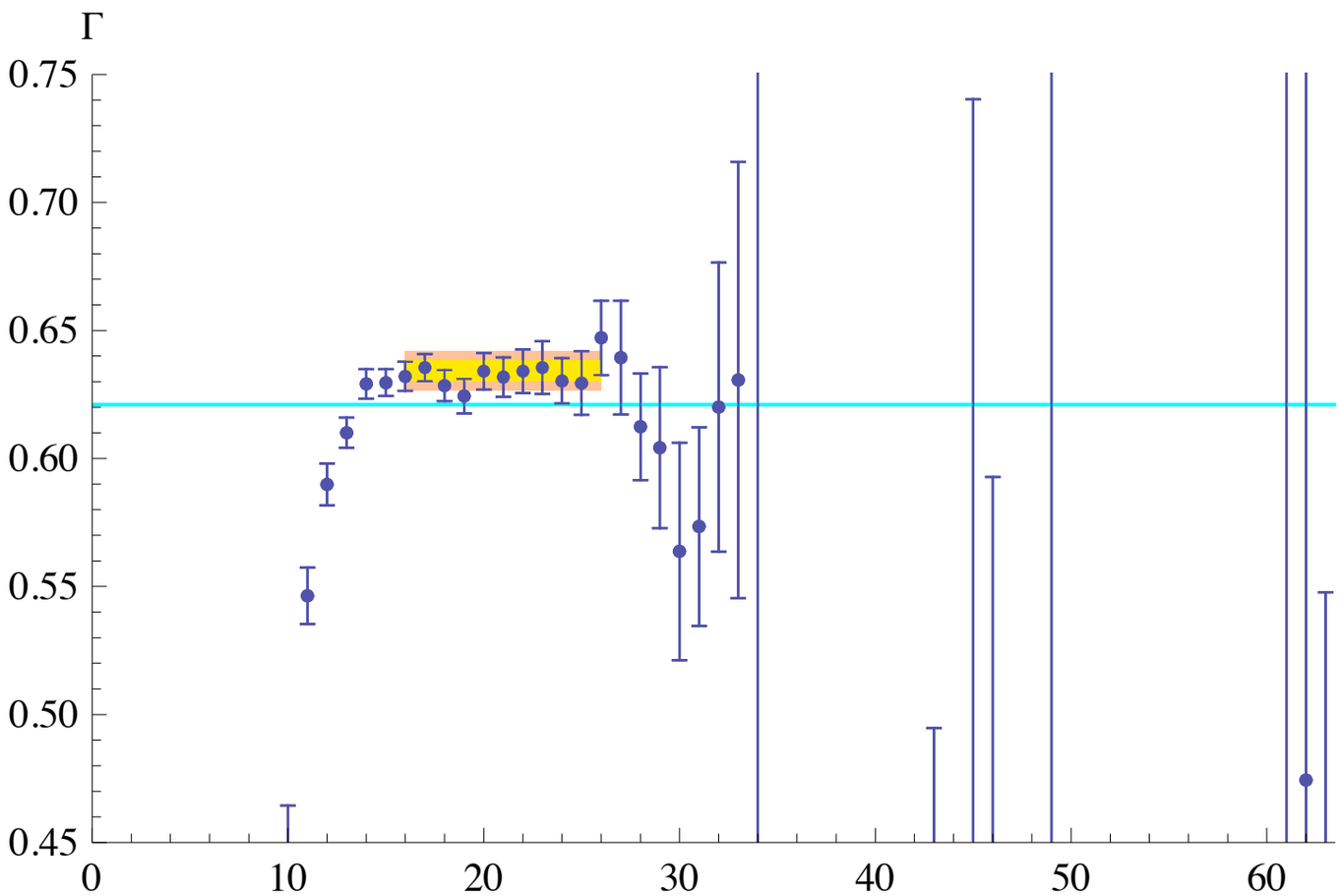
Baryon-Baryon Scattering



Three Baryon Systems

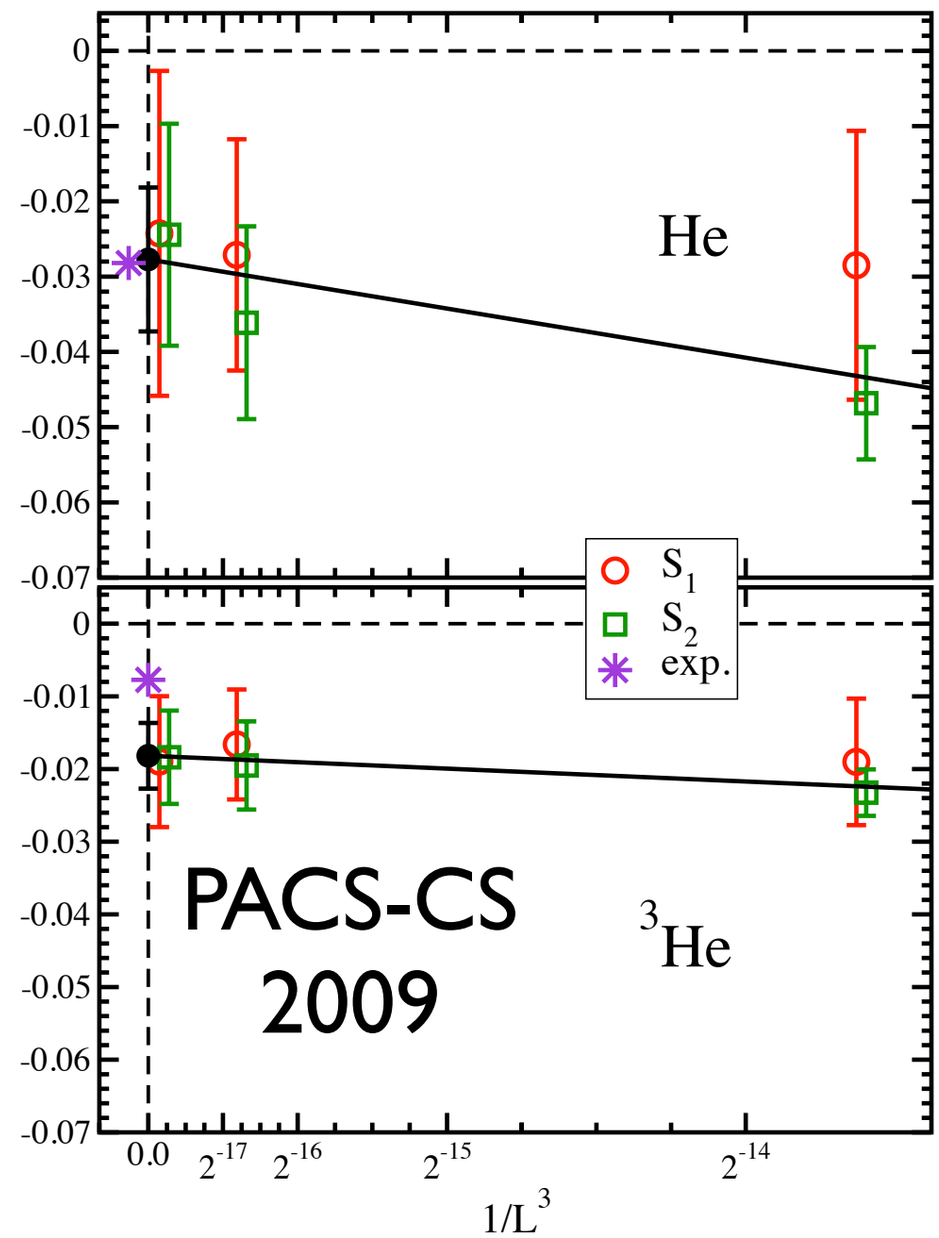


3-Baryons and the Triton Channel



$m_\pi \sim 390$ MeV

Dynamical



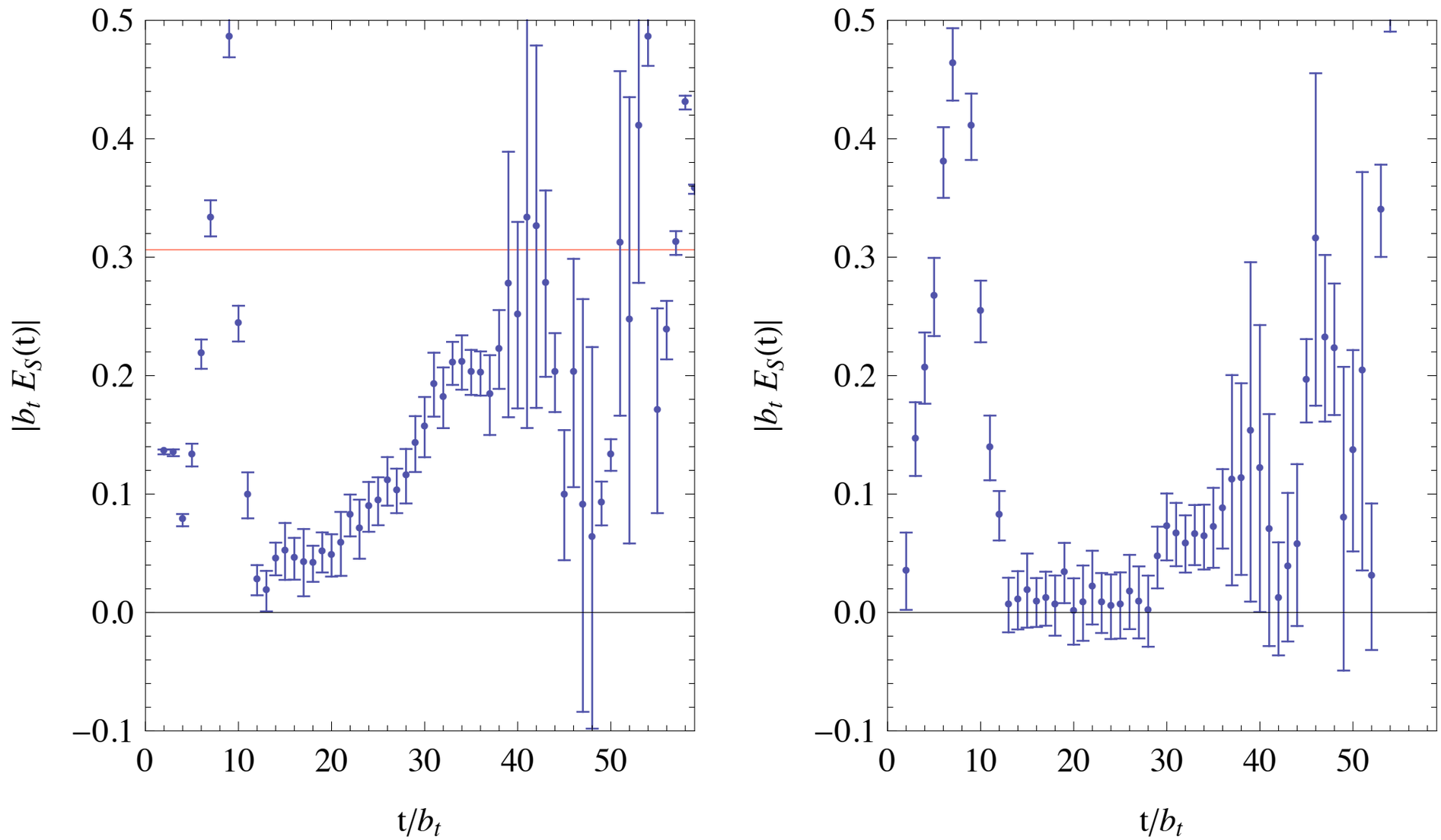
$m_\pi \sim 800$ MeV

Quenched

Three Baryon Systems

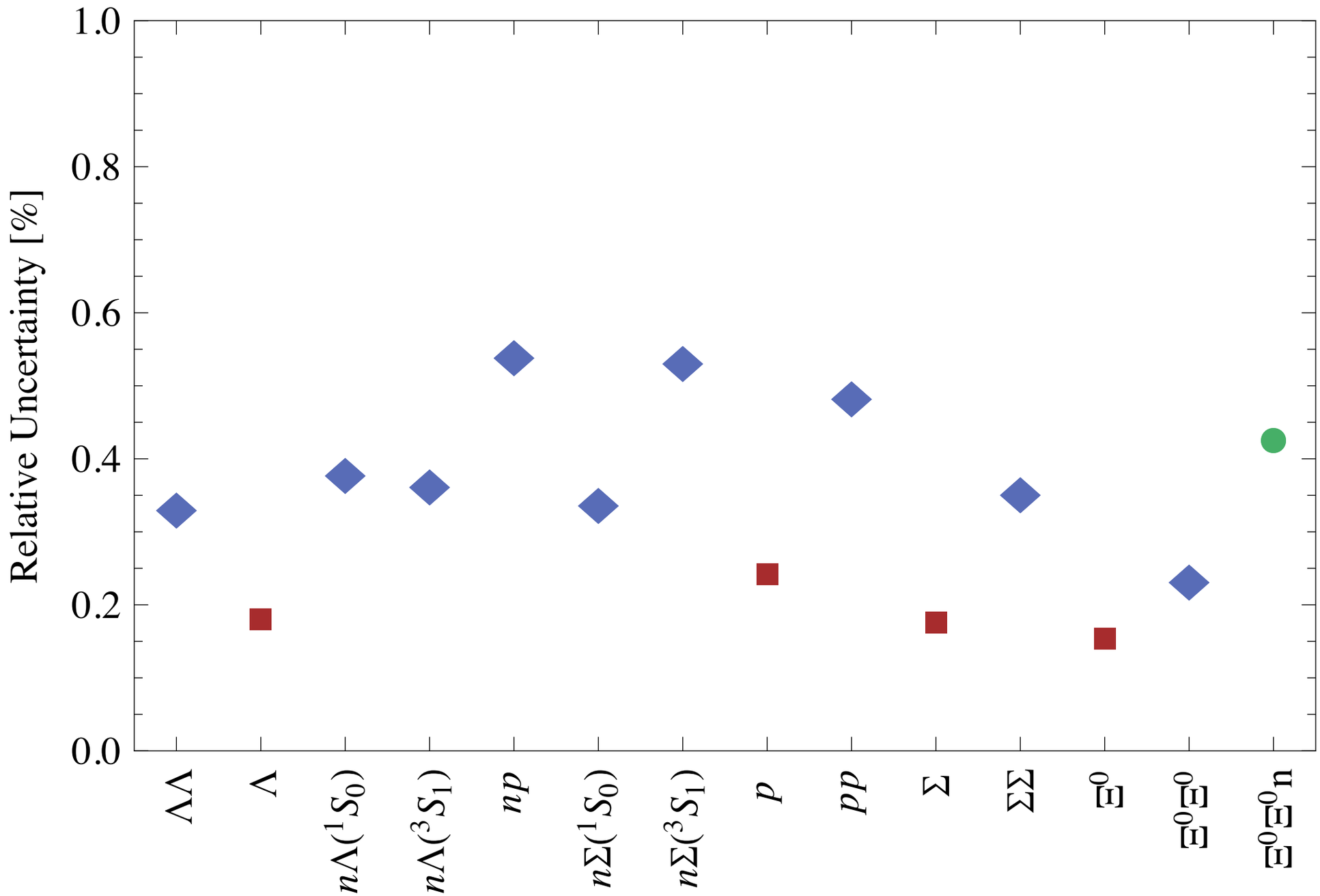
Signal-to-Noise Mass-Scale

$\Xi^0 \Xi^0 n$

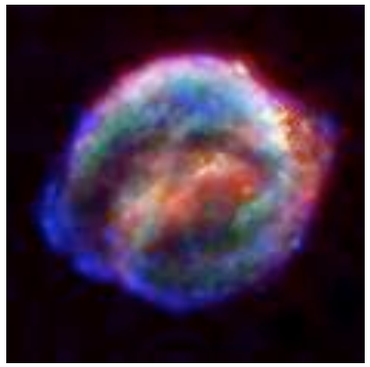


Optimize ``Golden Window''
for Nuclear Physics

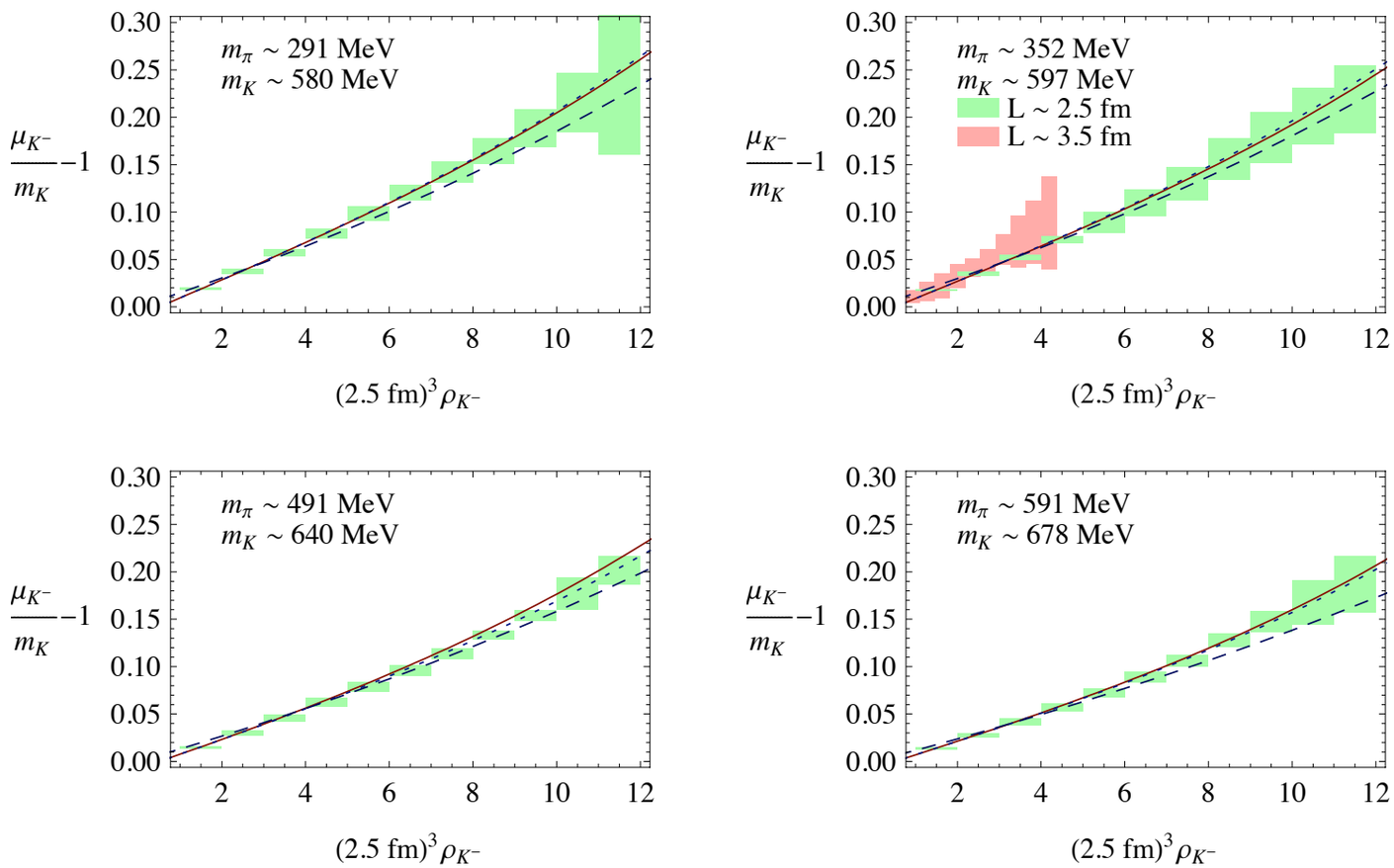
Uncertainty per Baryon



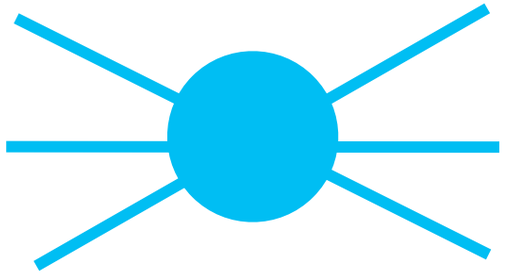
Bose-Einstein Condensates and Many-Body Systems

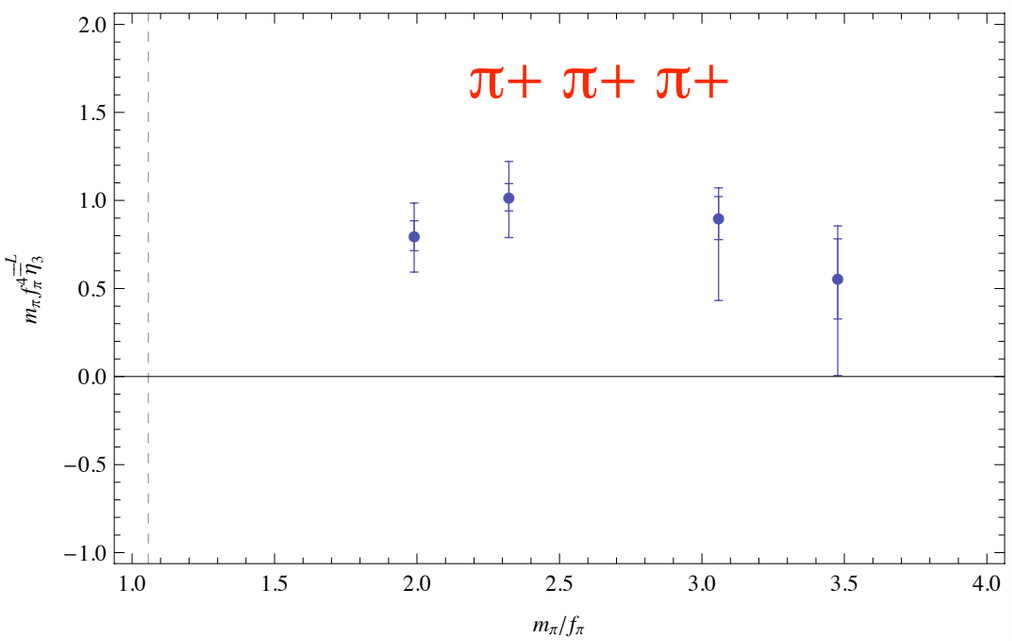


Kaon Condensates



Pion 3-Body Interaction

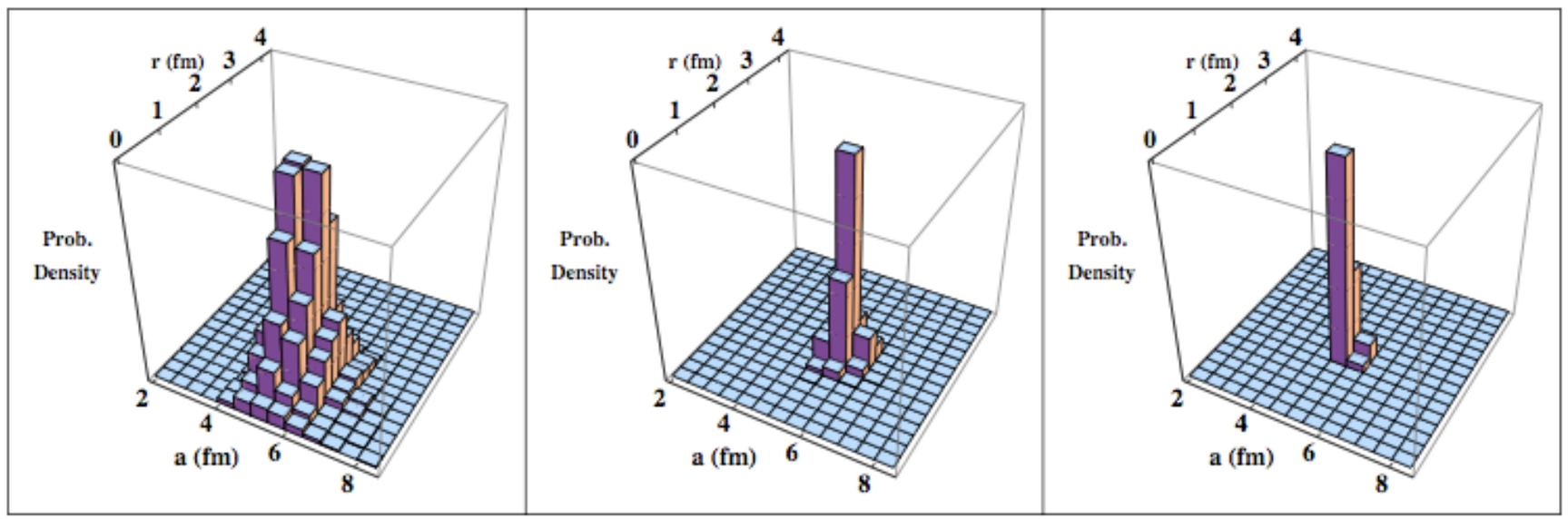


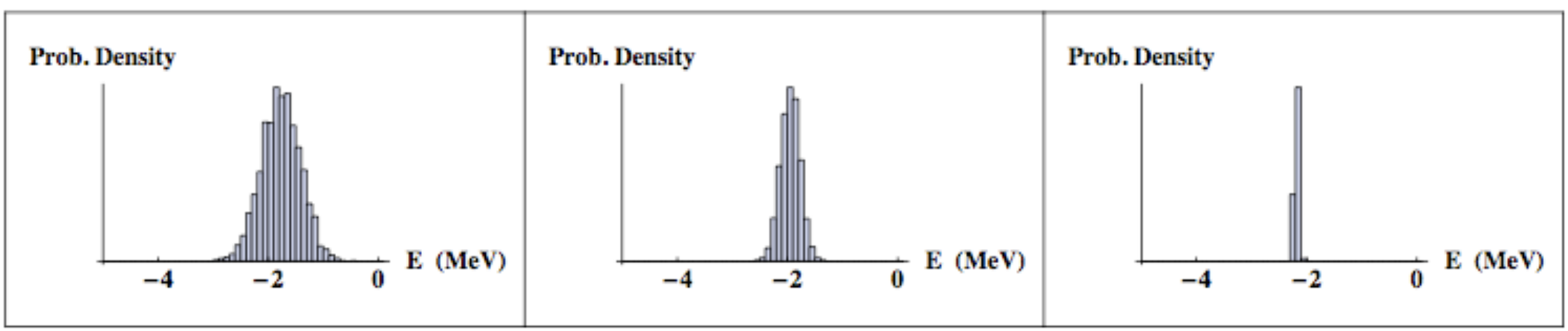


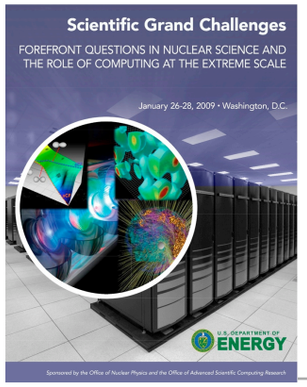
- Systems with kaons and pions : Detmold + Smigielski (to appear)
- Algorithm developed to include arbitrary numbers : Detmold+mjs

Fabricated Data for Optimization of Future Calcs.

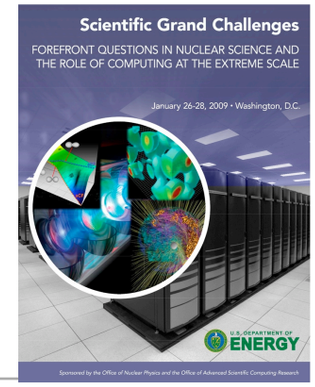
Precision Level	Bound State Energy (MeV)	1st ContinuumLevel (MeV)
0%	-3.147	4.005
1%	-3.111 ± 0.031	4.015 ± 0.040
5%	-2.95 ± 0.16	4.24 ± 0.20
10%	-2.66 ± 0.31	3.65 ± 0.40

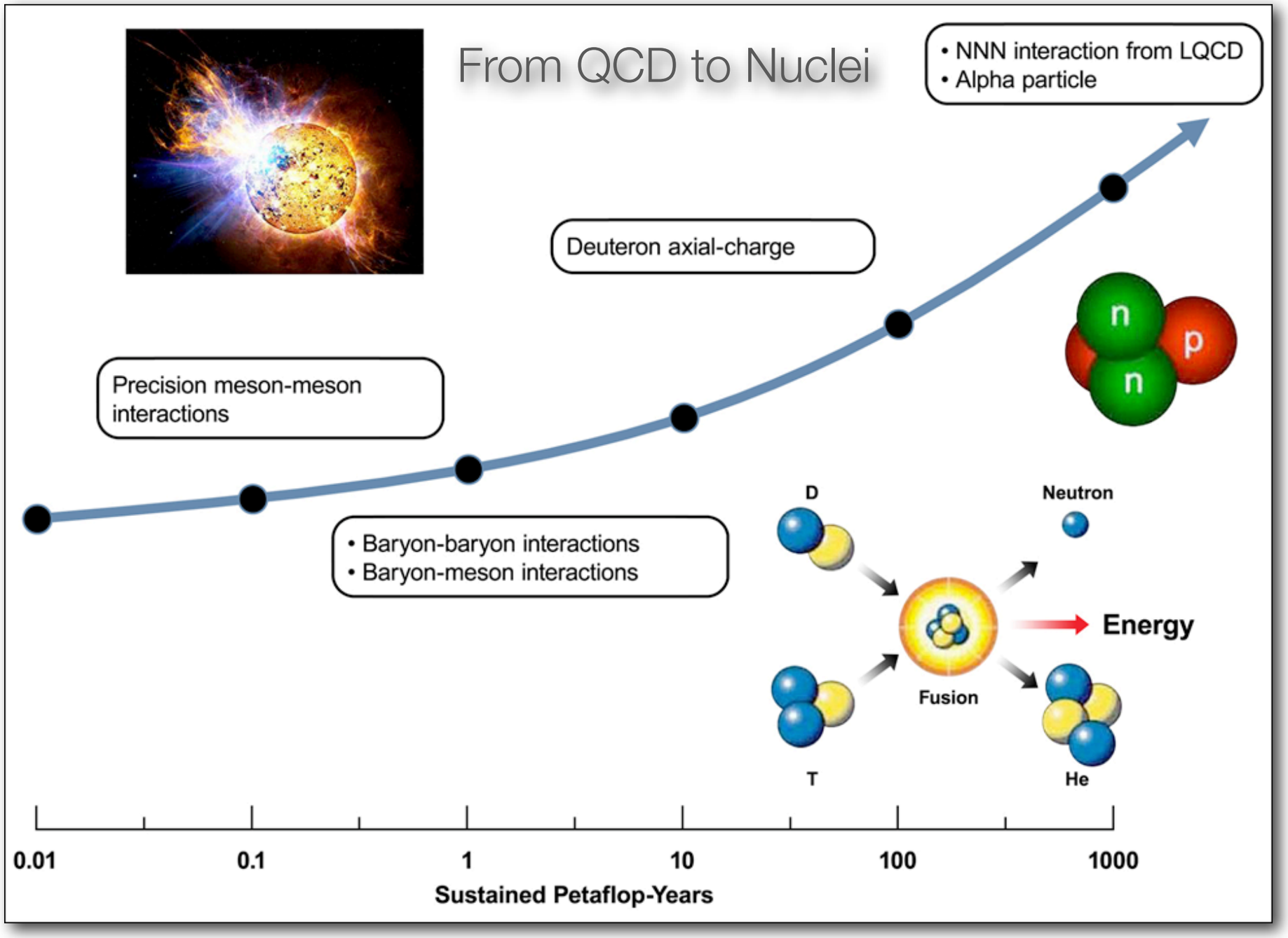


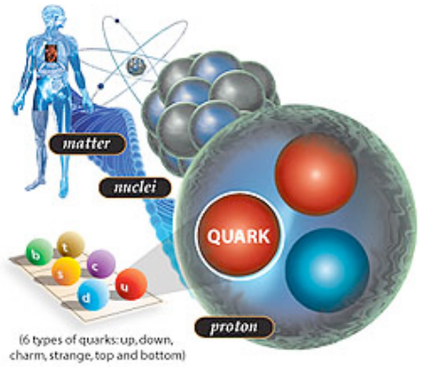


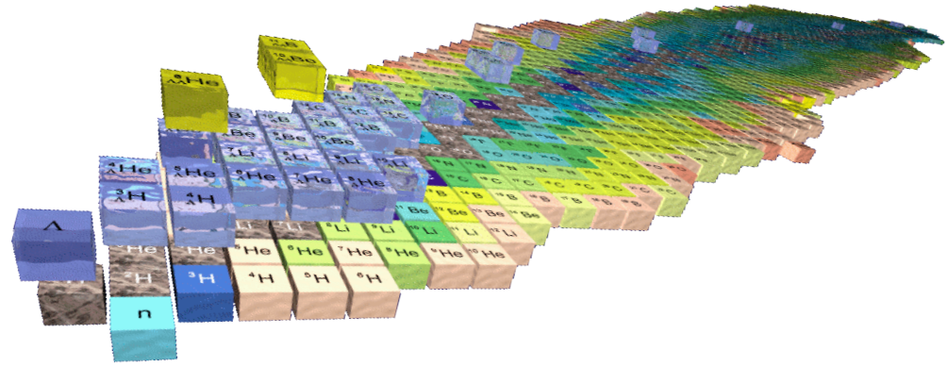


Computational Requirements









Lattice QCD is on the verge of making significant contributions to Nuclear Physics.

- The next few years will see remarkable things

- Lattice QCD calculations
  - at the physical pion mass,
  - in large volumes
  - at small lattice spacings

  are close at hand