Pentaquarks: Lattice overview

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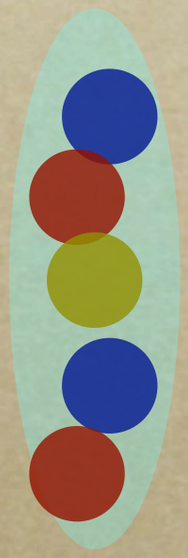
Pentaquarks in Lattice QCD

Pentaquark



?

Penta-gone

- *Indentifying resonances in Lattice QCD*
- *5Q studies to date*
  - *Opinions vary*
- *Isoscalar-3/2+: maybe exciting?*

Particle Energies in Lattice QCD

Write operator with correct quantum numbers

eg. Nucleon $\chi_N = \varepsilon^{abc}[u_a^T(x)C\gamma_5 d_b(x)]u_c(x)$

Measure 2-pt correlation function

$$\langle \chi(t)\bar{\chi}(0)\rangle = \sum_{n=0}^{\infty} \lambda_n \bar{\lambda}_n \exp(-E_n t)$$

$$\langle \chi'(t)\bar{\chi}'(0)\rangle = \sum_{n=0}^{\infty} \lambda'_n \bar{\lambda}'_n \exp(-E_n t)$$

Large Euclidean time → Low-lying energy states

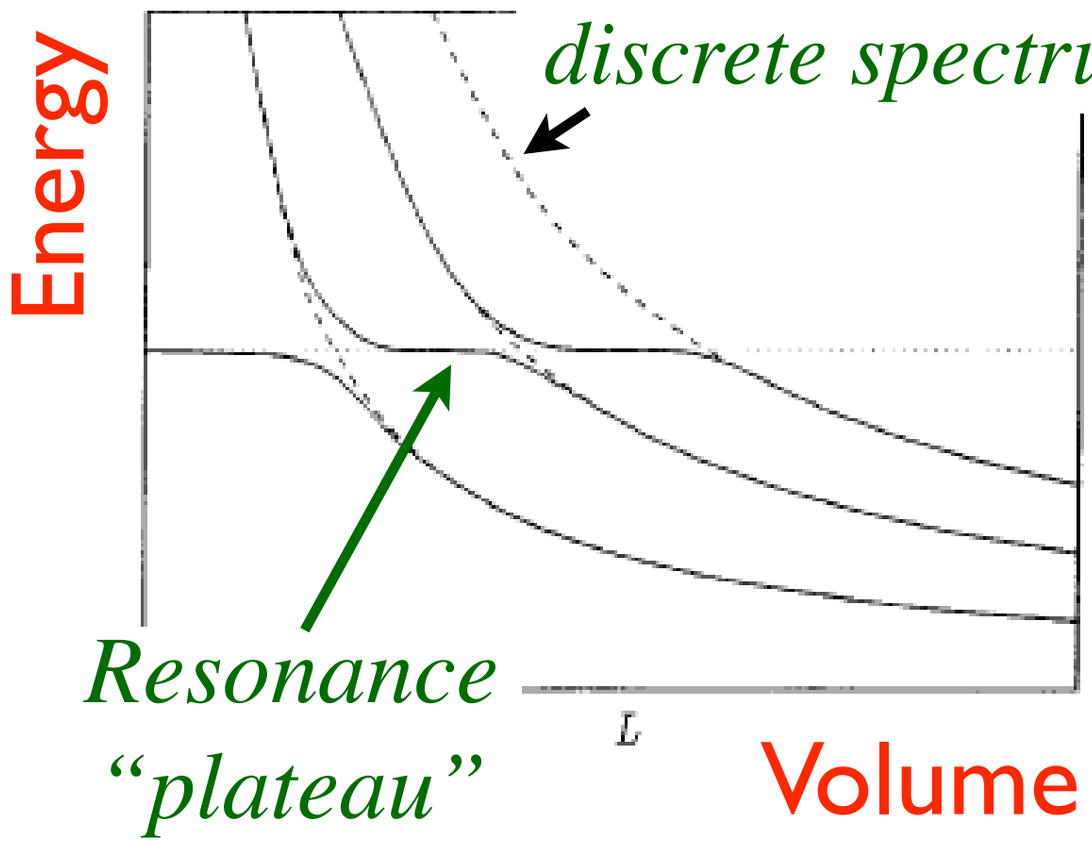
“Resonances” in Lattice QCD

- *Lowest-lying bound states: EASY*
- *“Unstable” particles: DIFFICULT*
- *M. Lüscher: Finite-volume analysis*
- *C. Michael: On-shell transition amplitudes*
  - *Tune 2-p energies to threshold,* Michael [Lat05]
- *Small volumes, heavy quarks*

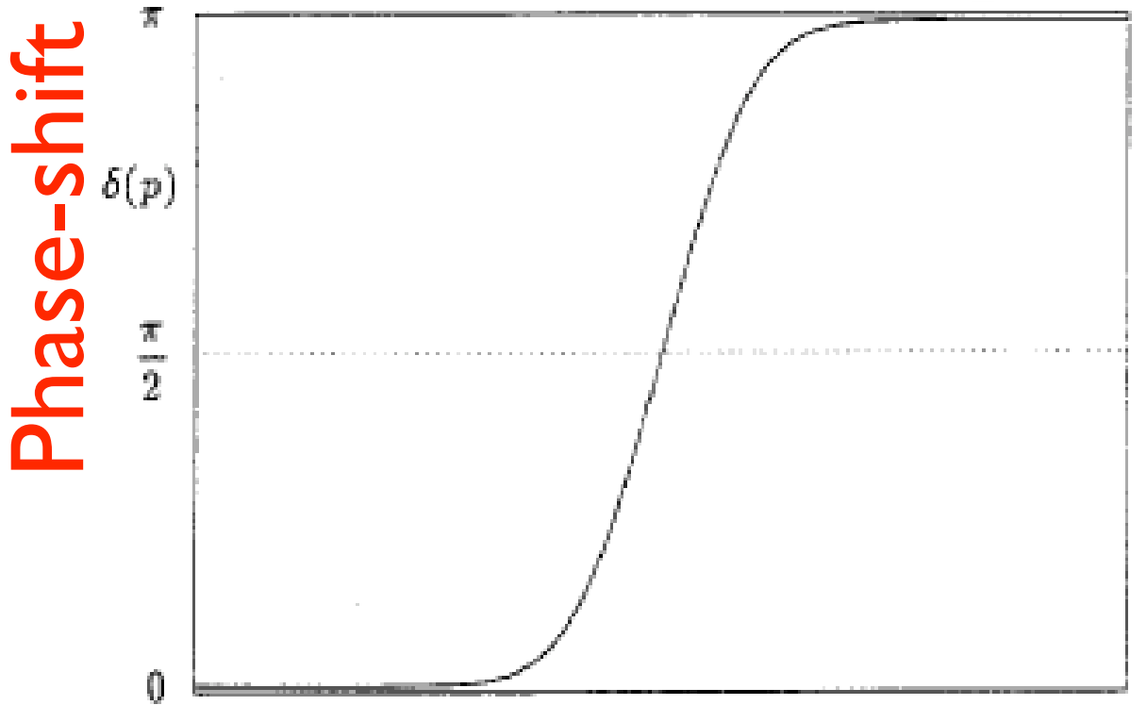
Lüscher Method

Map out volume-dependence of energy levels

2-particle discrete spectrum



Wiese [Lat88]



Resonance "plateau" for weakly interacting system ie. small width

Need phase-shift analysis for strongly-coupled systems

Spectral Weight

$$\langle \chi(t)\bar{\chi}(0)\rangle = \sum_{n=0}^{\infty} \lambda_n \bar{\lambda}_n \exp(-E_n t)$$

Single particle states

$\lambda_n \bar{\lambda}_n \sim 1$

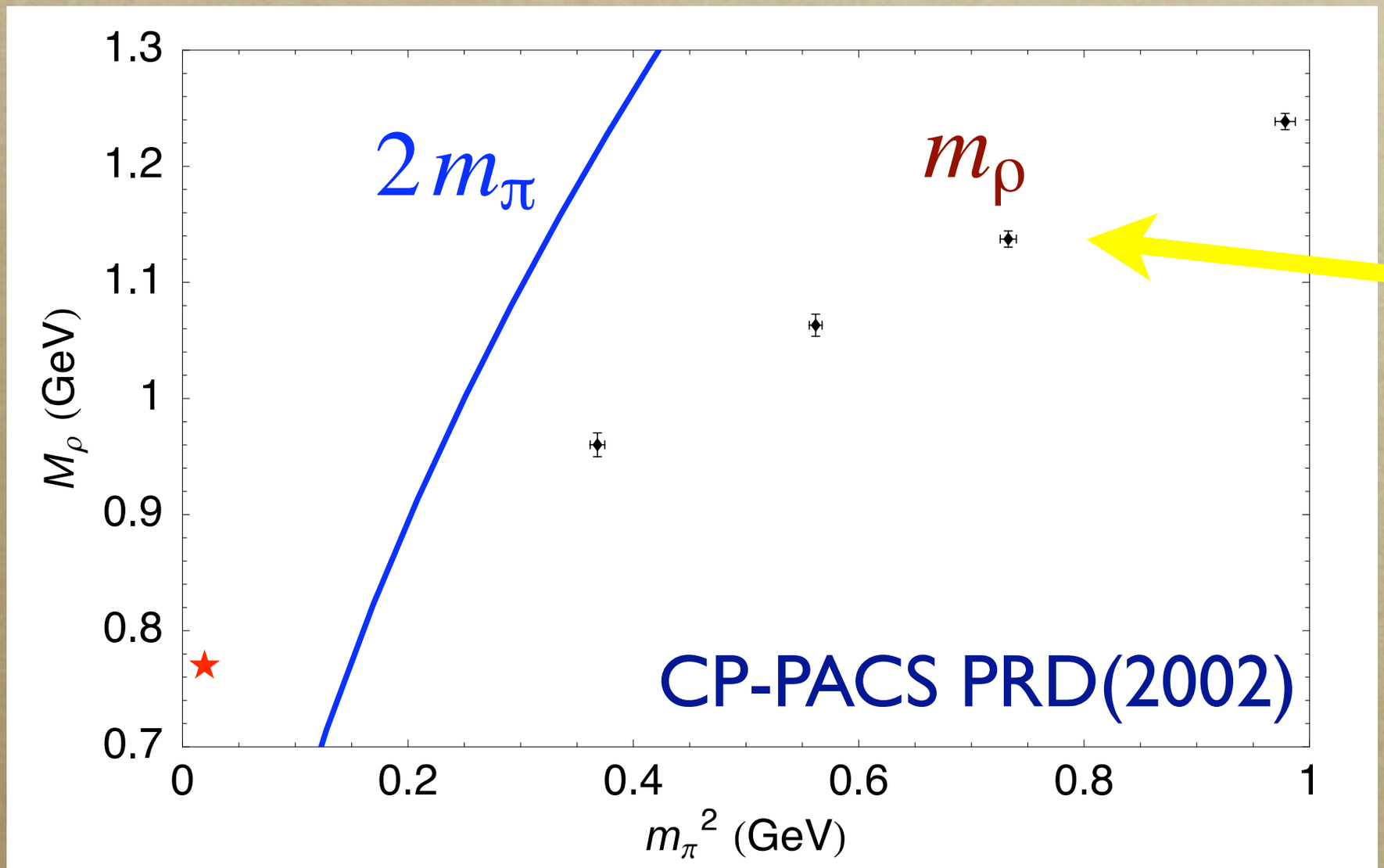
Two particle states

$\lambda_n \bar{\lambda}_n \sim L^{-3}$

In principle, volume dependence of spectral weight can distinguish 1– or 2–particle states

"Heavy" quark masses

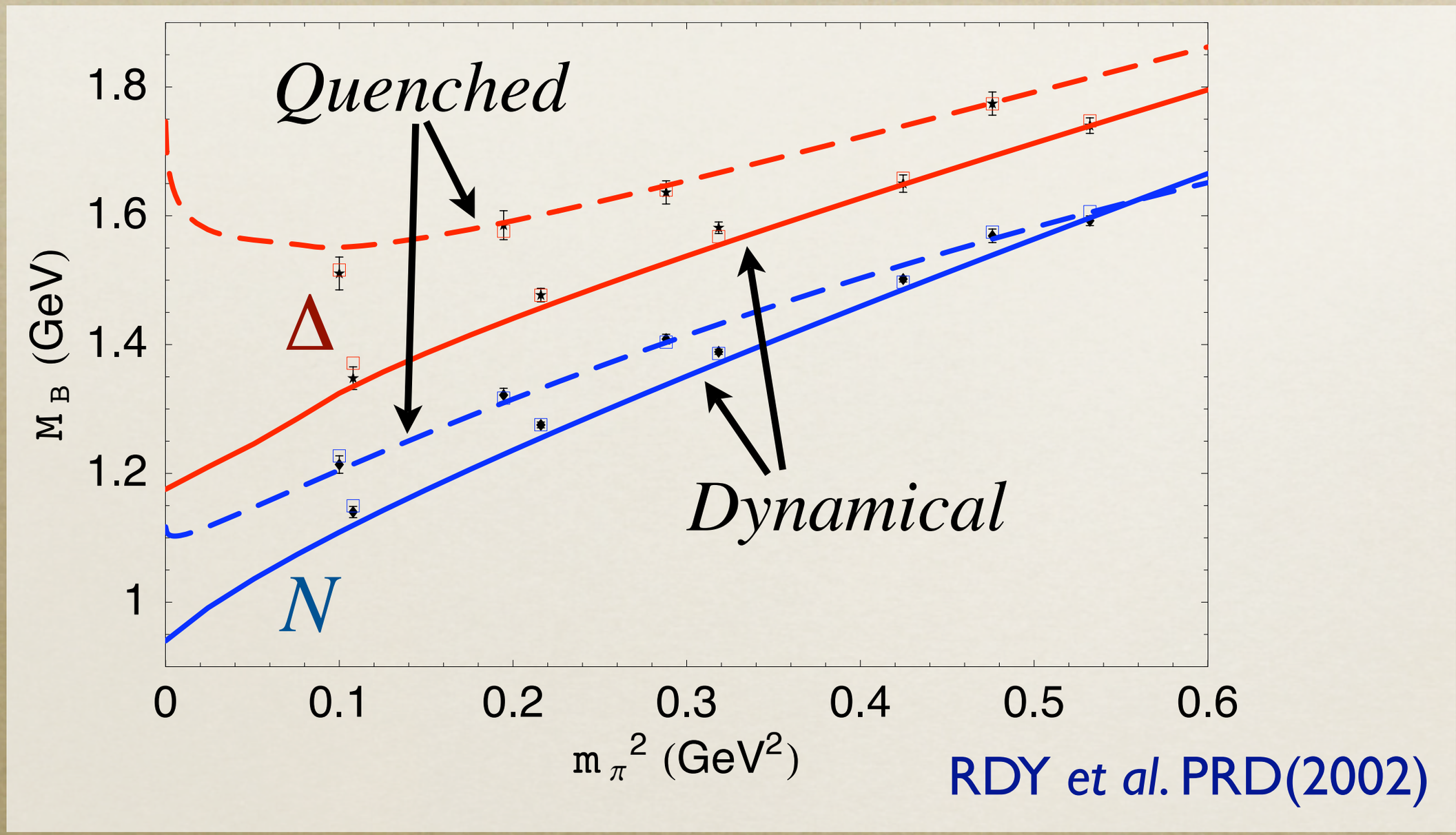
Standard resonances, like rho and Delta, are typically bound at simulation quark masses



Easy to observe rho

Similarly for all other excited states

Quenching and Chiral Extrap.



Pentaquarks: chiral extrapolation unknown!

Potentially large quenching artifacts

Spin-1/2

Spin-1/2

"Probable"

Study	***Evidence***	***$I(J)^P$***
Csikor et al. (2003)	*Lightest 5q-state is 0^-*	*$0(1/2)^-$*
Sasaki	*"–"parity above NK, operator small NK overlap*	*$0(1/2)^-$*
Chiu & Hsieh	*Uncertain analysis*	*$0(1/2)^+$*
Alexandrou & Tsapalis	*Volume-independence of spectral weight*	*$0(1/2)^-$*
Takahashi et al.	*V-indep. of spec. weight for 1st excited state*	*$0(1/2)^-$*

Spin-1/2

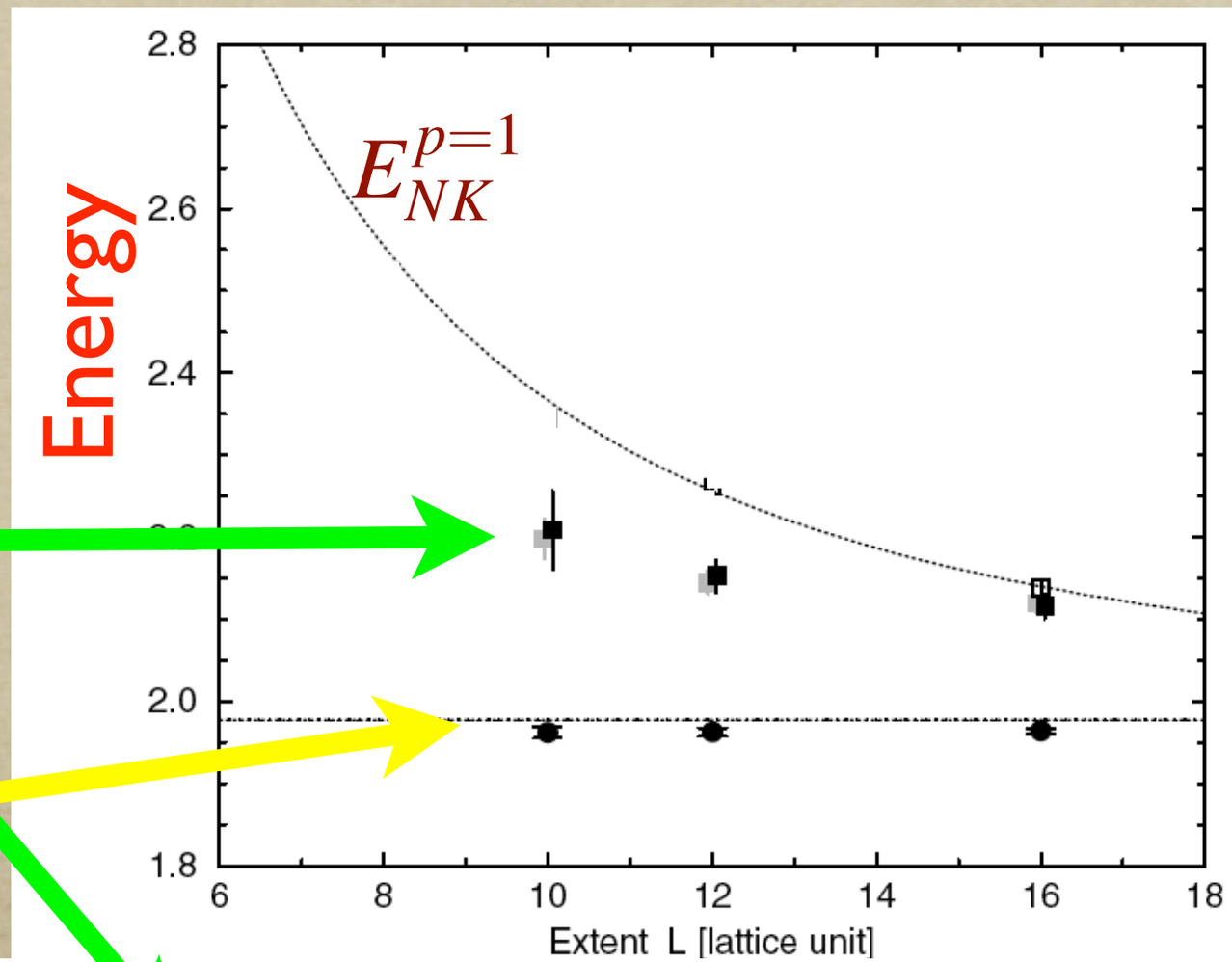
"Probably not"

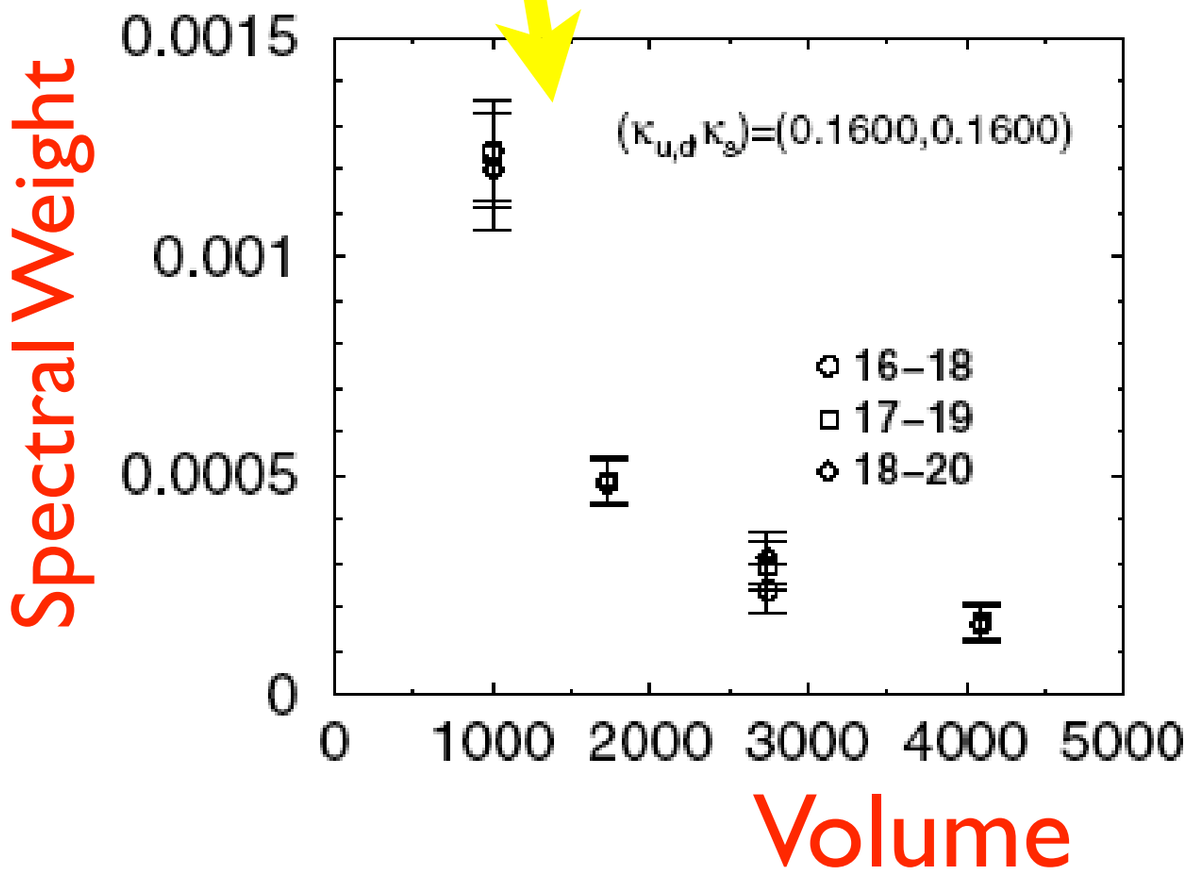
Study	***Evidence (lack of)***
Mathur et al.	*Volume dep. consistent with scattering state*
Ishii et al.	*HBC rules out localised 5Q state*
Lasscock et al.	*No anomalous states beyond 2-particle spectrum*
Csikor et al. (2005)	*No anom. states beyond 2-p Vol dep. ➙ 2-p.*
Holland & Juge	*No anomalous states beyond 2-particle spectrum*

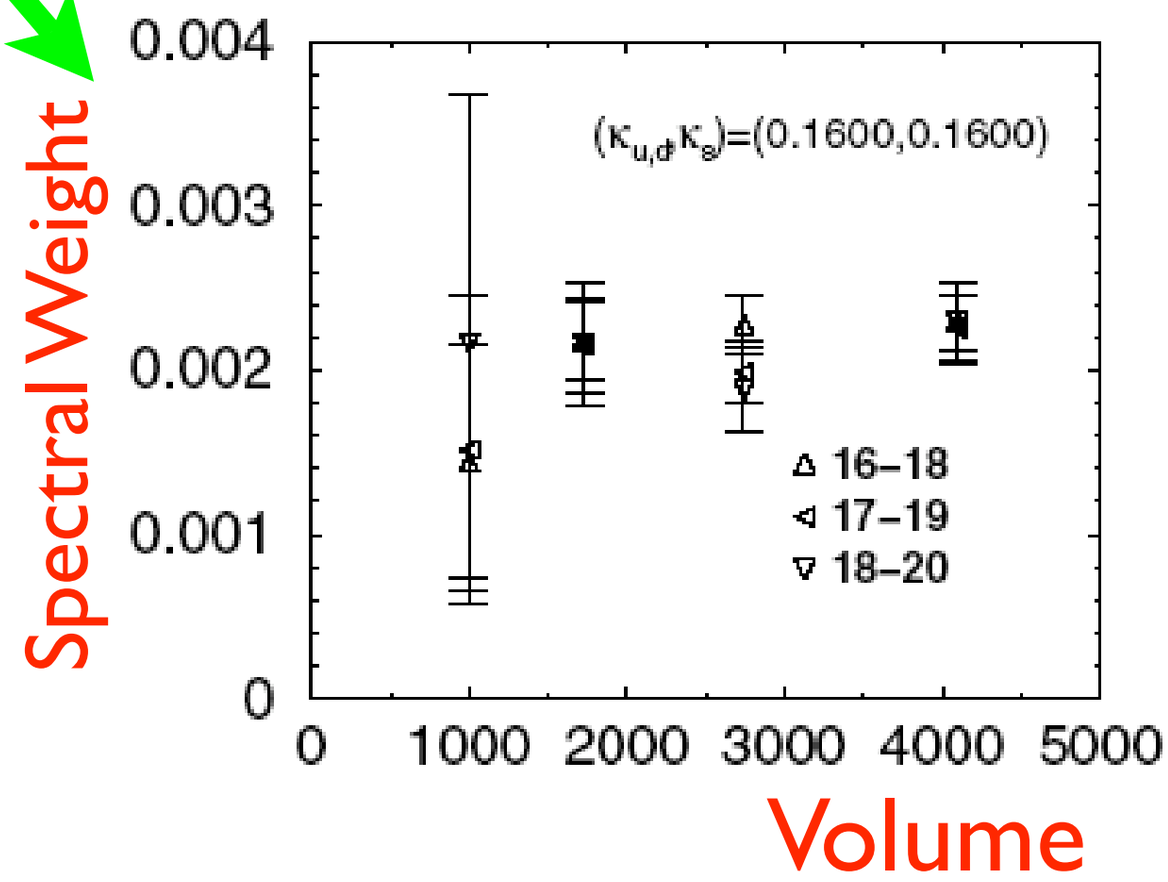
Takahashi *et al.* PRD(2005)

5Q — excited state

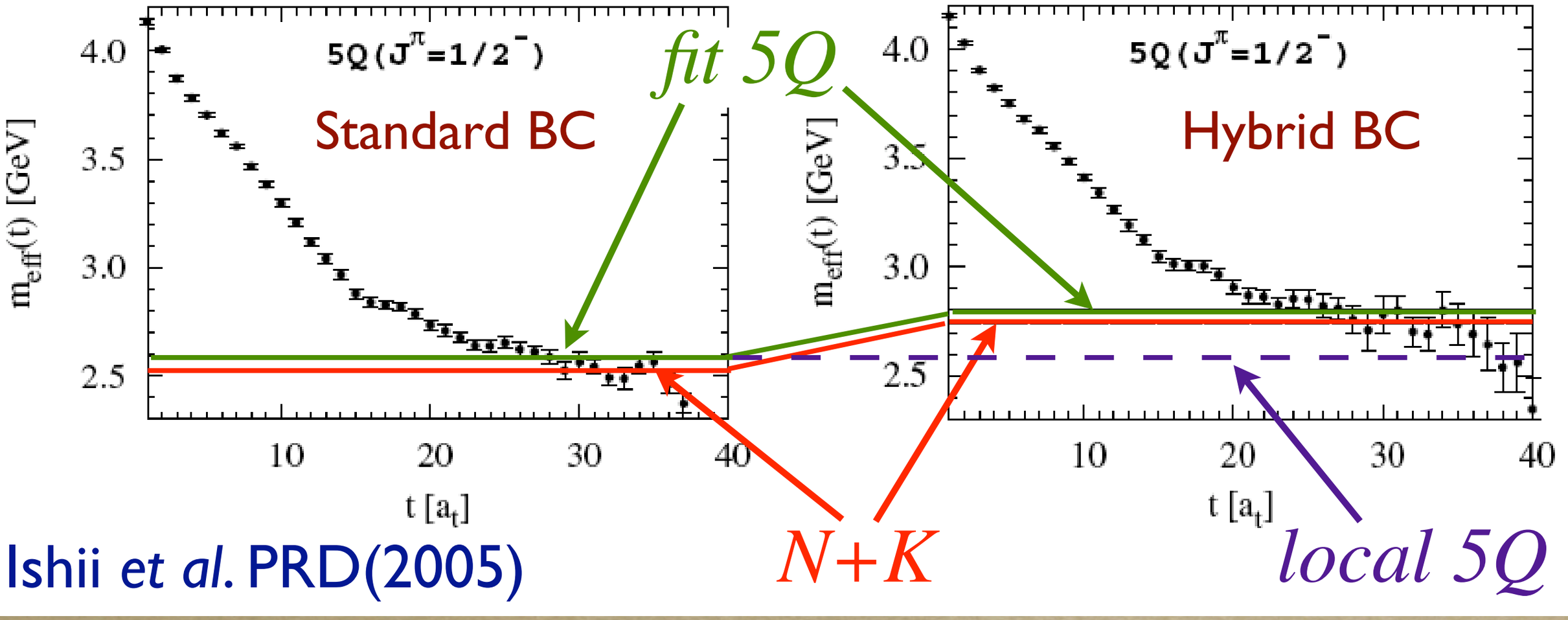
5Q — ground state







Hybrid BCs



Ishii *et al.* PRD(2005)

u, d, s periodic

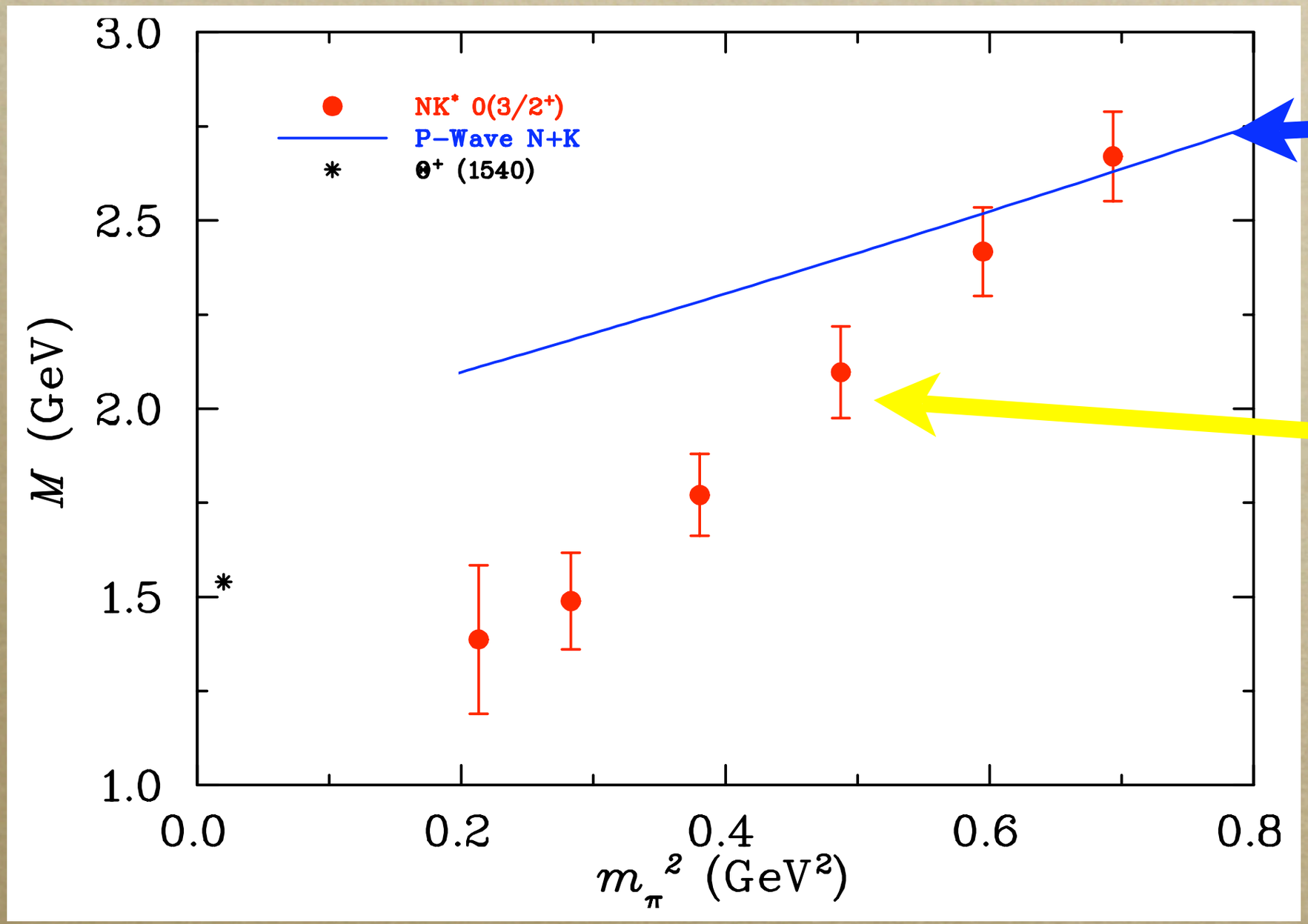
u, d antiperiodic
s periodic

Local 5Q state ruled out in ground state

Spin-3/2

5Q Bound-state?

$$I(J^{\pi}) = 0(\tfrac{3}{2}^{+})$$



***NK* Energy**

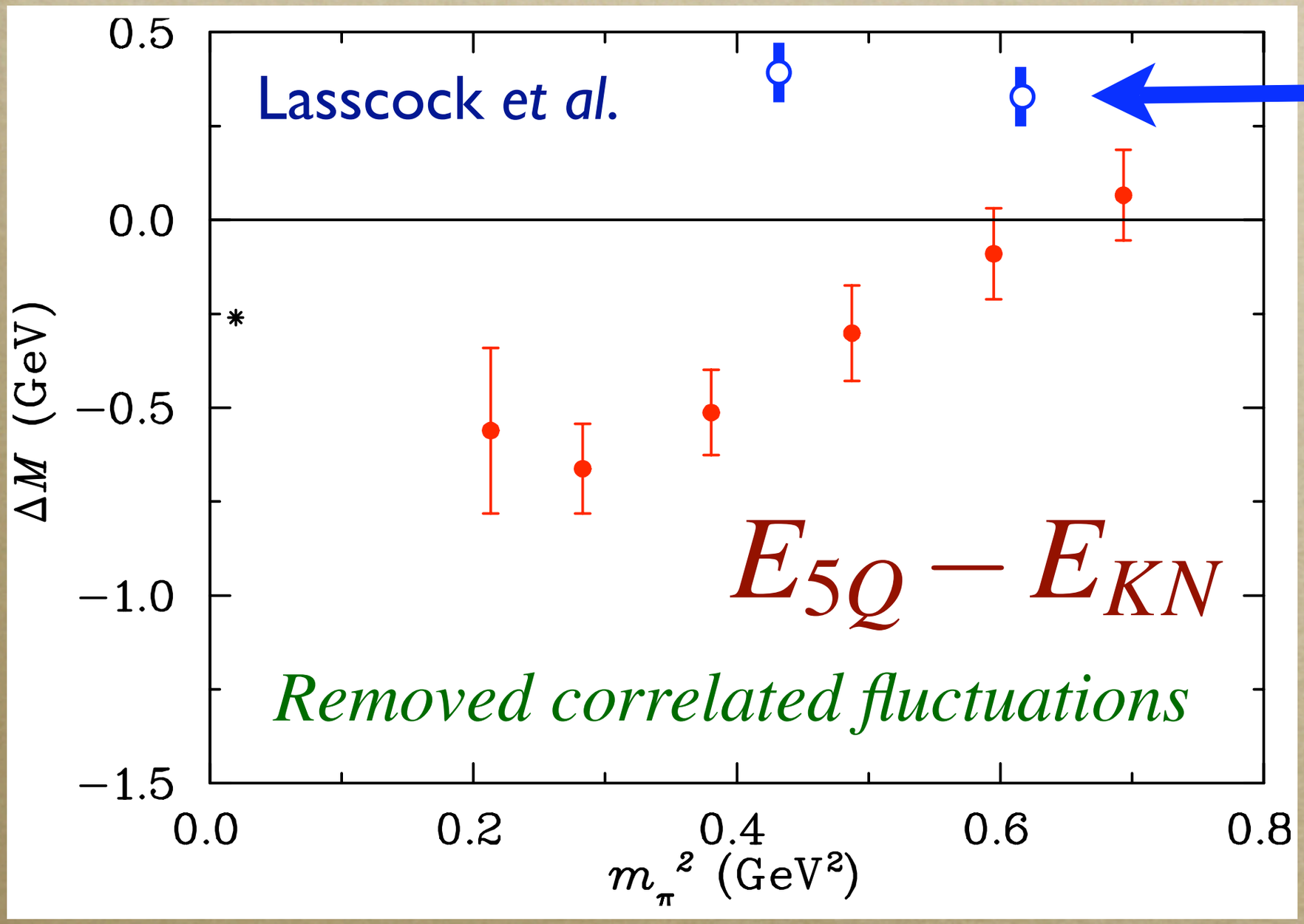
5Q System

Operator
"NK"*

Lasscock *et al.* hep-lat/0504015

Far below threshold!

Mass-splitting analysis



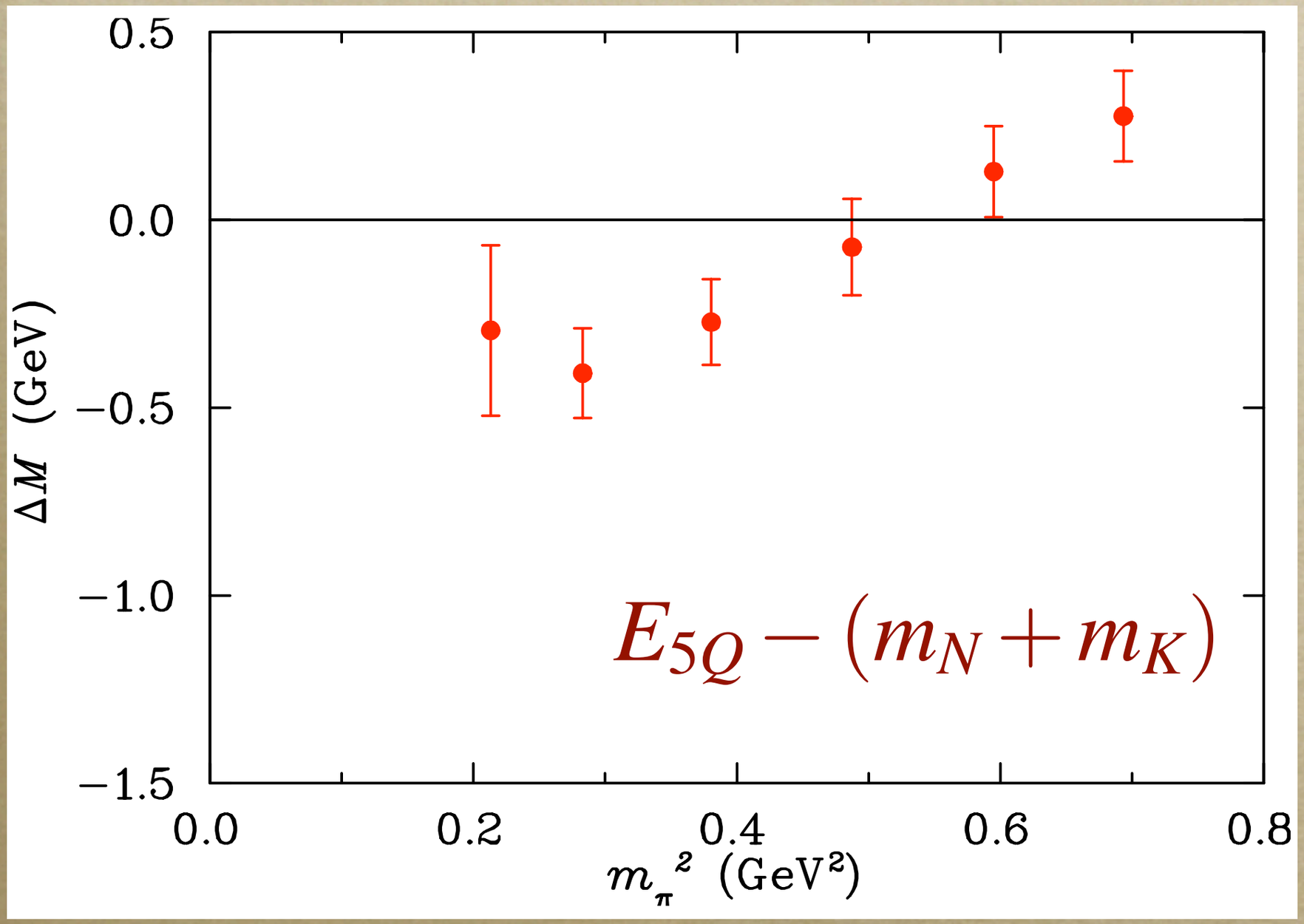
Ishii *et al.*
hep-lat/0504015

Smaller volume
Coarser lattice

Binding mechanism

$\sim 500\,\mathrm{MeV}$

Volume effect?



Potentially stable on larger volumes

Summary

- *Study of (exotic) resonance physics is a challenging problem for lattice spectroscopy*
- *No definitive answer, as yet*
- *Further investigation could be interesting*
- *Dynamical fermions, please!*

References — Pentaquark

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