Joseph Wasem, Michael Buchoff, Tom Luu
Lawrence Livermore National Laboratory

Omega Baryon Interactions with Lattice QCD

LLNL-PRES-533073

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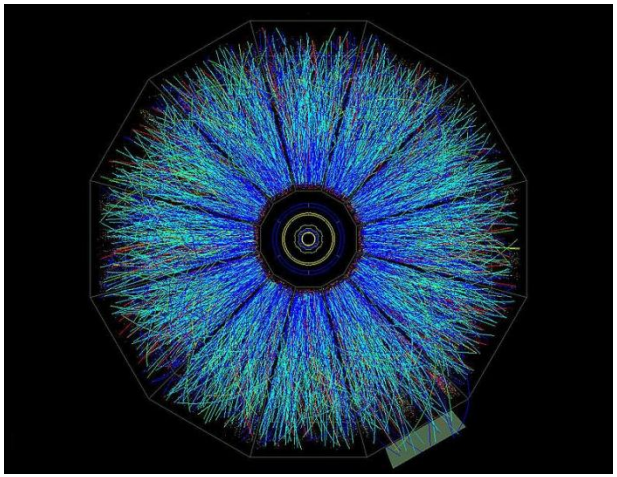
Omega Physics



- Experiments beginning to probe hyperon physics
- Omega physics least understood

- Good testing ground for nuclear physics lattice calculations
- "Nuclear-like" scattering "at the physical point."

Omega Model Calculations

- Two model calcs disagree:

$$\Delta E_{\Omega\Omega} = 43 \pm 18\,\mathrm{MeV} \quad \text{(Quark Disloc./Color Screening Model)}$$

F. Wang, J.-l. Ping, G.-h. Wu, L.-j. Teng, and J. T. Goldman, Phys. Rev. **C51**, 3411 (1995), nucl-th/9512014.

$$\Delta E_{\Omega\Omega} = -116\,\mathrm{MeV} \quad \text{(SU(3) Chiral Quark Model)}$$

Z. Y. Zhang, Y. W. Yu, C. R. Ching, T. H. Ho, and Z.-D. Lu, Phys. Rev. **C61**, 065204 (2000).

- Would like a model-independent resolution to this question…

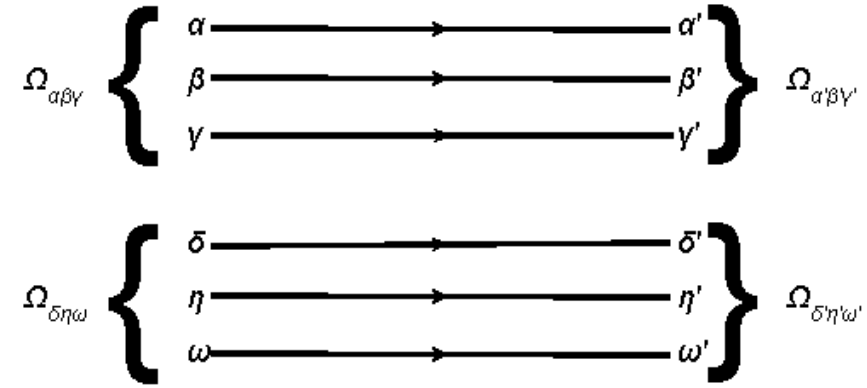
Interpolating Operators

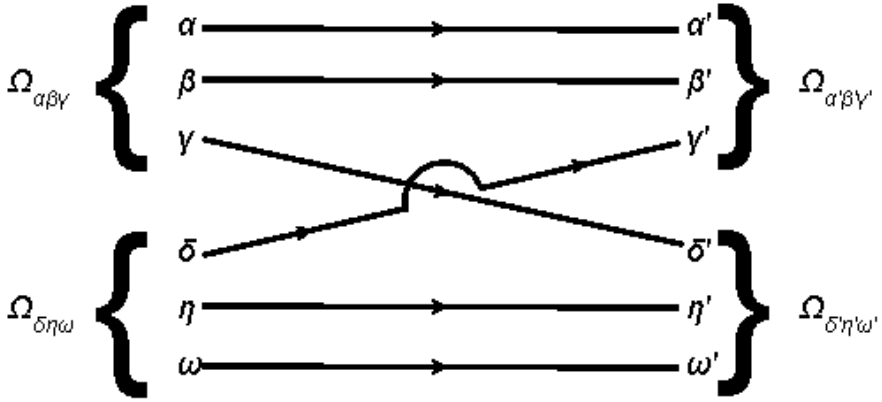
- Discretization breaks O(3) symmetry to octahedral subgroup

$\Gamma\ (L \neq \infty)$	$J\ (L = \infty)$	
A_1^+	0	← $\Omega\Omega$ Ground
T_1^-	1	
E^+	2	← $\Omega\Omega$ Excited
T_2^+	2	← $\Omega\Omega$ Excited
G_1^+	$\frac{1}{2}$	
H^+	$\frac{3}{2}$	← Ω

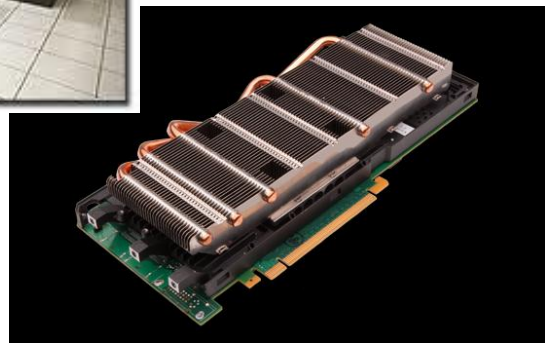
- Different linear combinations of $\Omega_{\alpha\beta\gamma}$ are in different irreps/embeddings/rows
  - S. Basak et al., Phys. Rev. D72, 074501.

Steps to a Lattice Omega-Omega

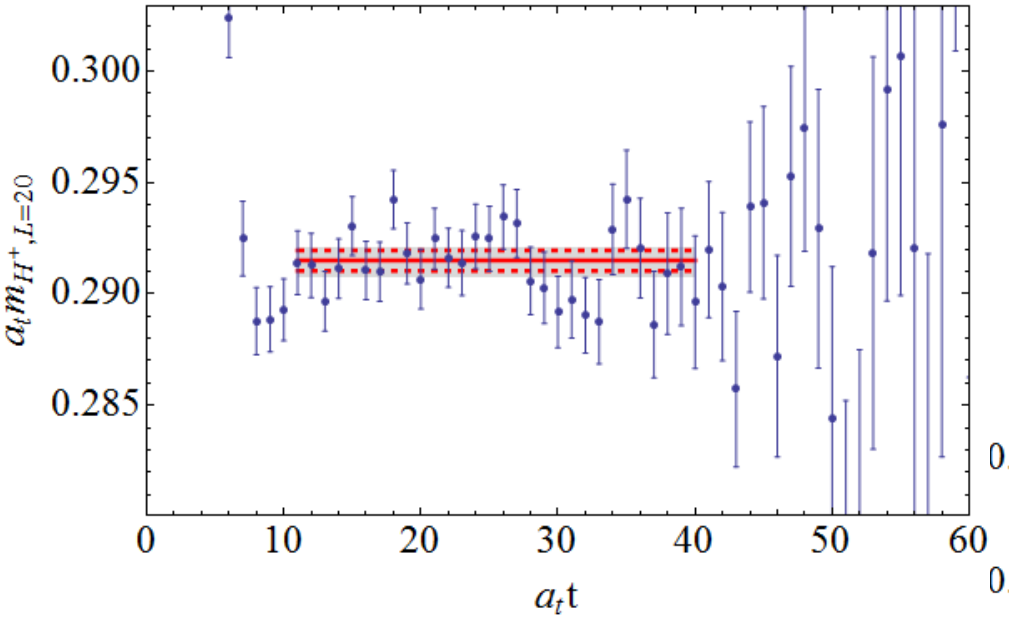


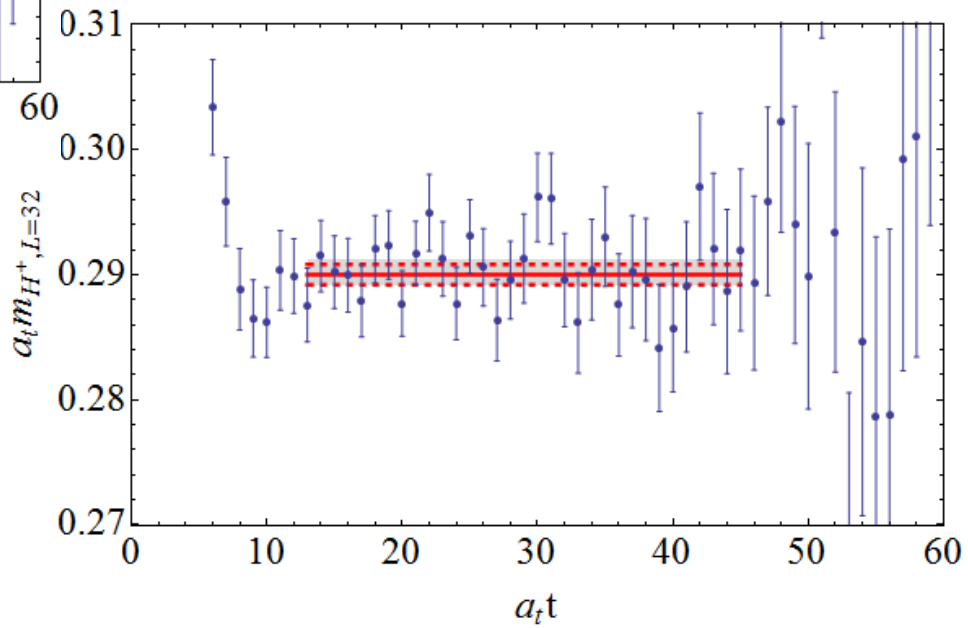


- Gauge Configurations
  - Two ensembles used:
    - $20^3 \times 256$ [$(2.5\text{ fm})^3 \times 9.2\text{ fm}$]
    - $32^3 \times 256$ [$(3.9\text{ fm})^3 \times 9.2\text{ fm}$]
  - $m_\pi \sim 390$ MeV

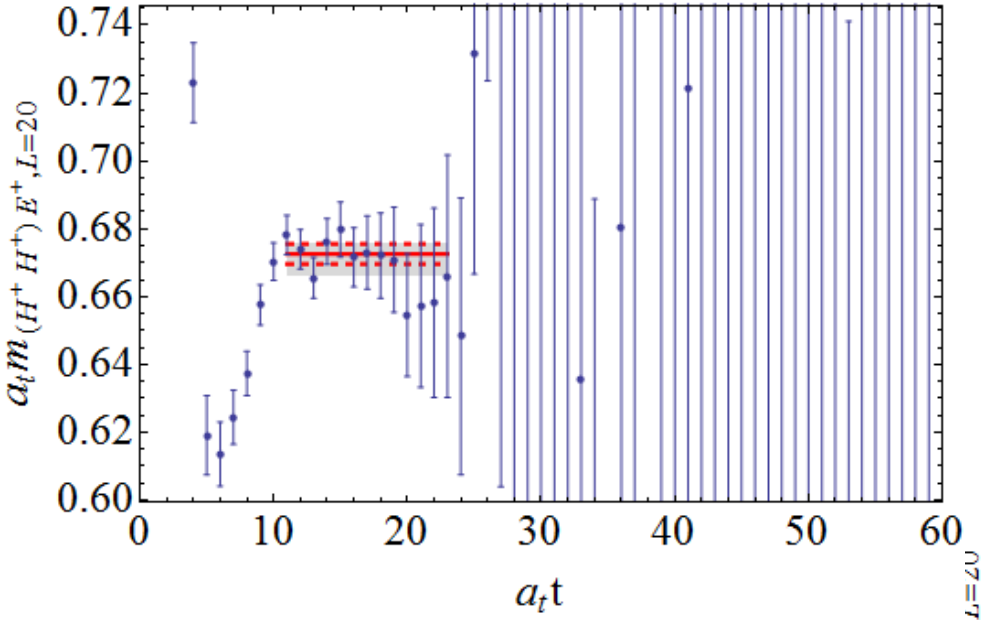


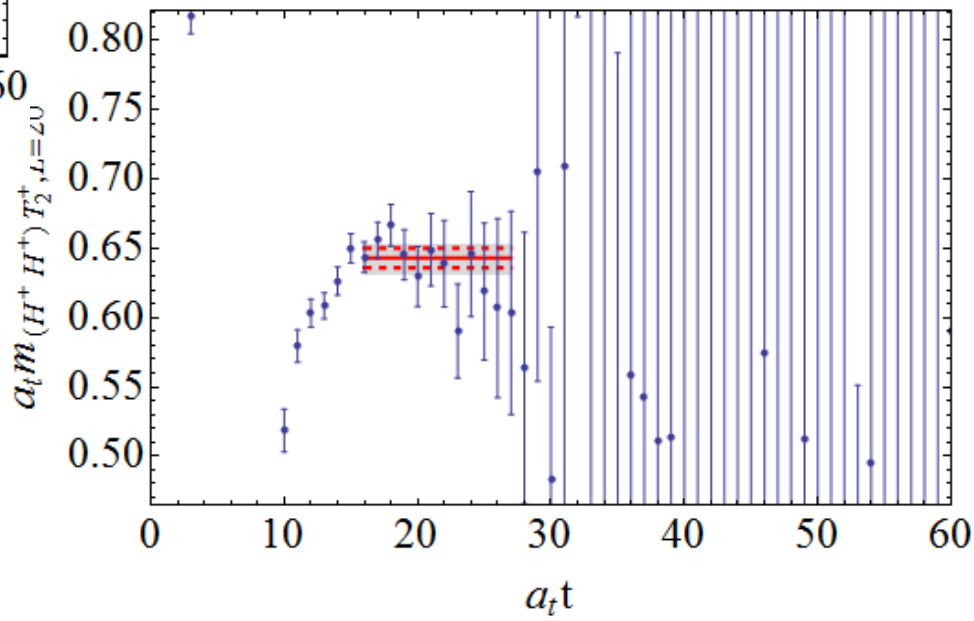
H^+ Lattice Data (Single Ω)



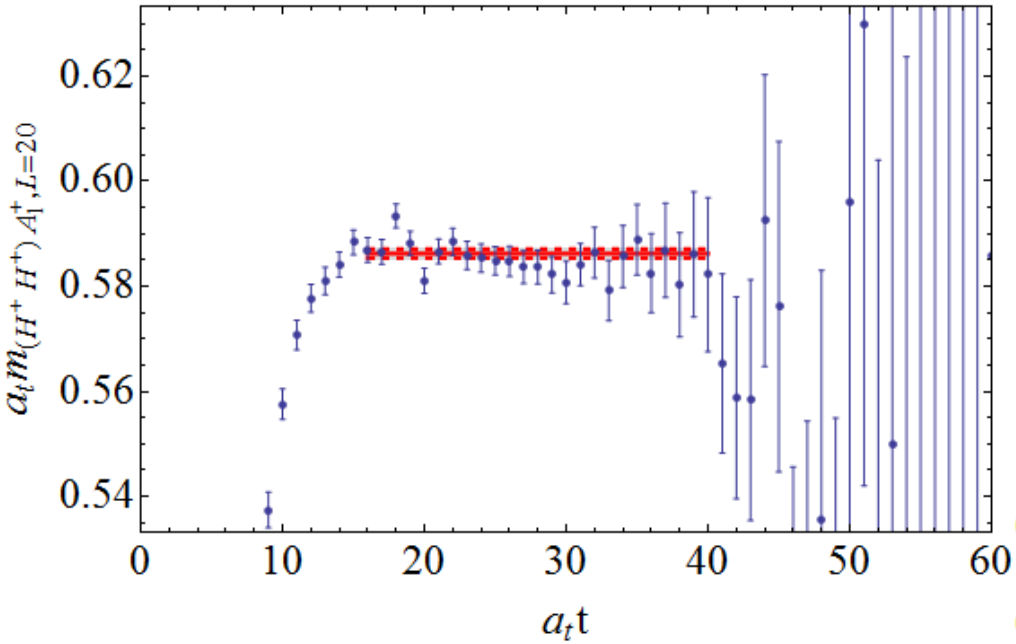


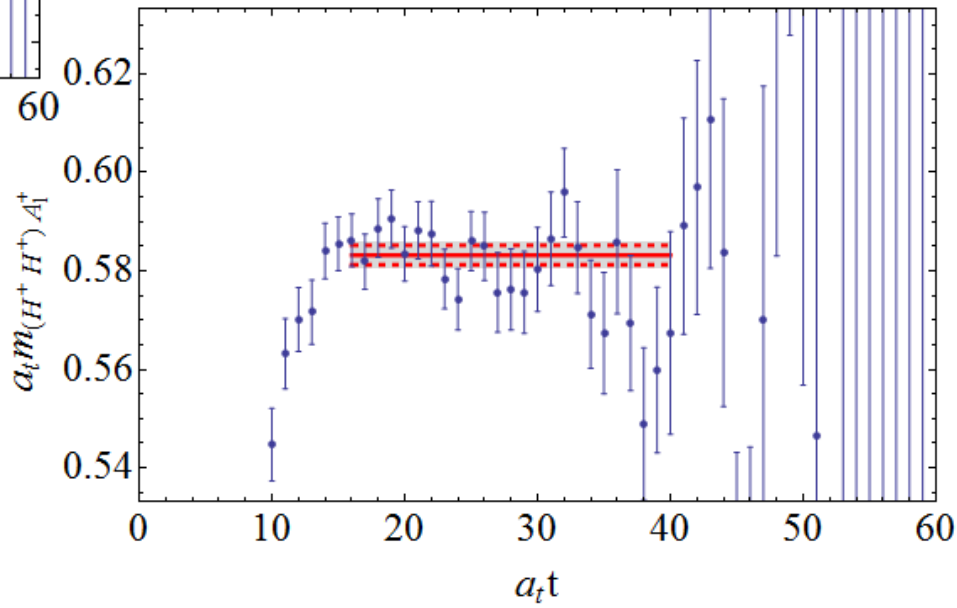
E^+ & T_2^+ Lattice Data (Two Ω)



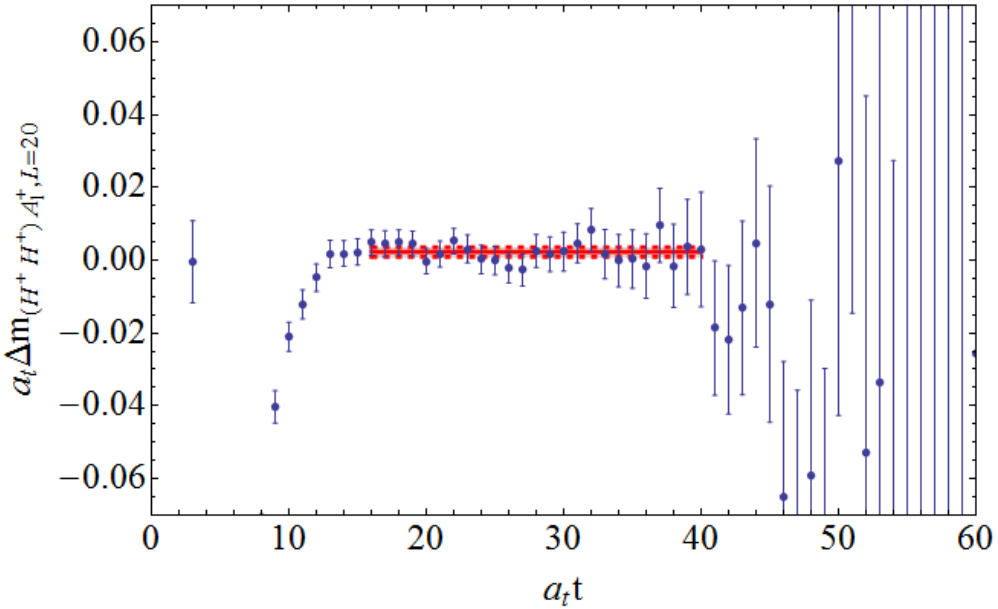


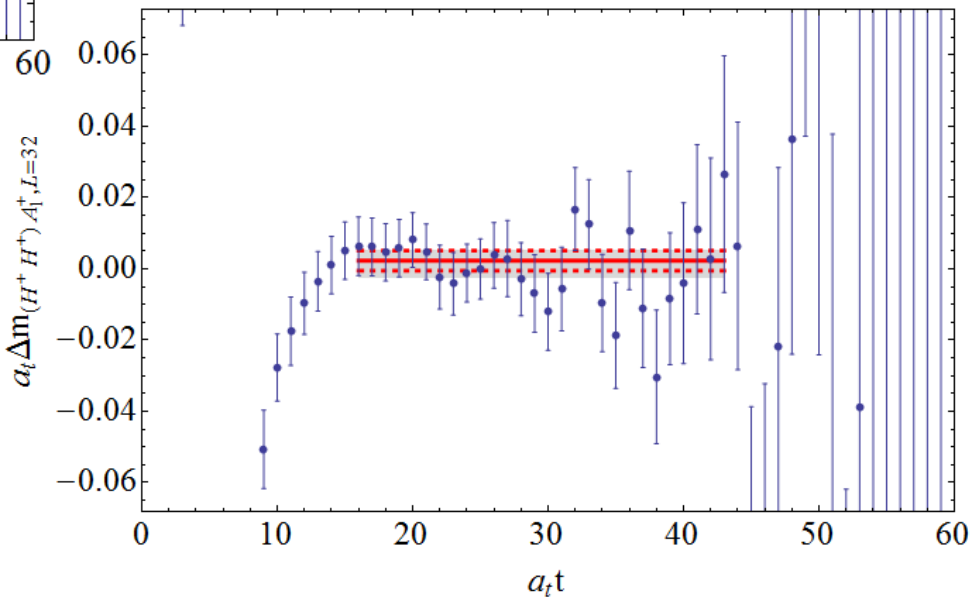
A_1^+ Lattice Data (Two Ω)





A_1^+ ΔE Plot


0.06
0.04
0.02
0.00
−0.02
−0.04
−0.06
0
10
20
30
40
50
60
a_tt
$a_t\Delta m_{(H^+H^+)A_1^+,L=20}$

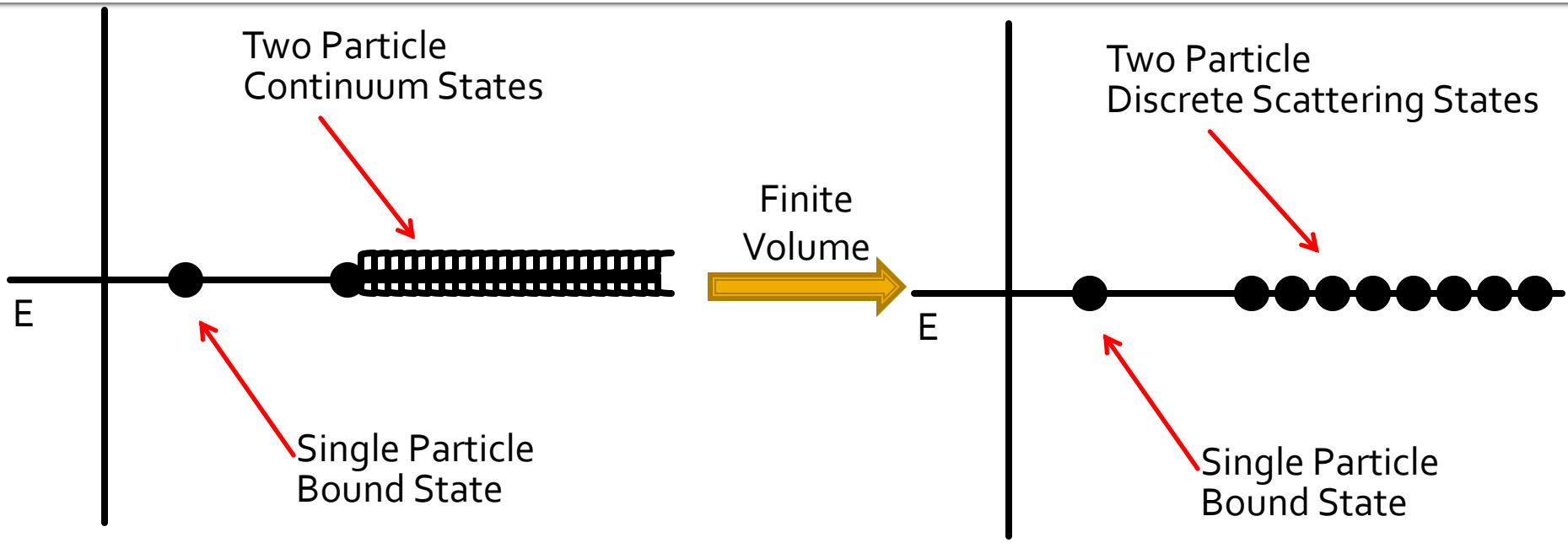

0.06
0.04
0.02
0.00
−0.02
−0.04
−0.06
0
10
20
30
40
50
60
a_tt
$a_t\Delta m_{(H^+H^+)A_1^+,L=32}$

Lattice Data

Irrep	Lattice Size	a_tE	$\sigma_{E,stat.}$	$\sigma_{E,sys.}$	χ^2/dof	Q	$a_t\Delta E$	$\sigma_{\Delta E,stat.}$
H^+	$20^3 \times 256$	0.291501	0.000457	$^{+0.000099}_{-0.000268}$	1.003	0.460		
	$32^3 \times 256$	0.290001	0.000804	$^{+0.000418}_{-0.000001}$	0.850	0.708		
A_1^+	$20^3 \times 256$	0.586235	0.000843	$^{+0.000091}_{-0.000348}$	1.105	0.327	0.00323	0.00124
	$32^3 \times 256$	0.583224	0.002002	$^{+0.000577}_{-0.000680}$	1.086	0.350	0.00322	0.00257
T_2^+	$20^3 \times 256$	0.642961	0.007136	$^{+0.002502}_{-0.005120}$	0.925	0.514	0.05996	0.00719
E^+	$20^3 \times 256$	0.67256	0.00293	$^{+0.00013}_{-0.00329}$	0.500	0.916	0.08956	0.00307

- Ω mass ~1640 MeV
- $\Omega\,\Omega$ energy > 2x Ω mass
  - Scattering state, not bound

Scattering at Finite Volume

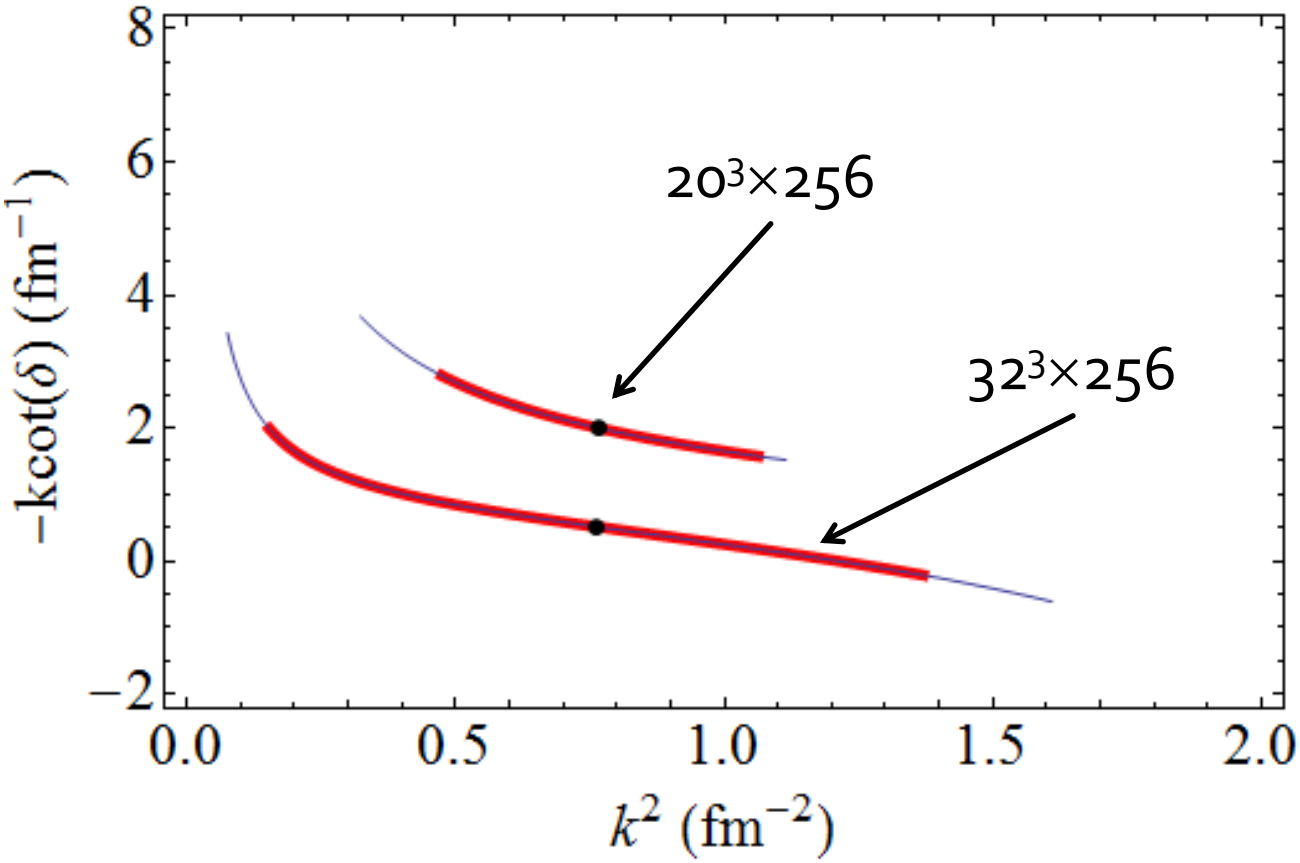


$$E = \sqrt{k^2 + m_A^2} + \sqrt{k^2 + m_B^2} = \Delta E + m_A + m_B$$

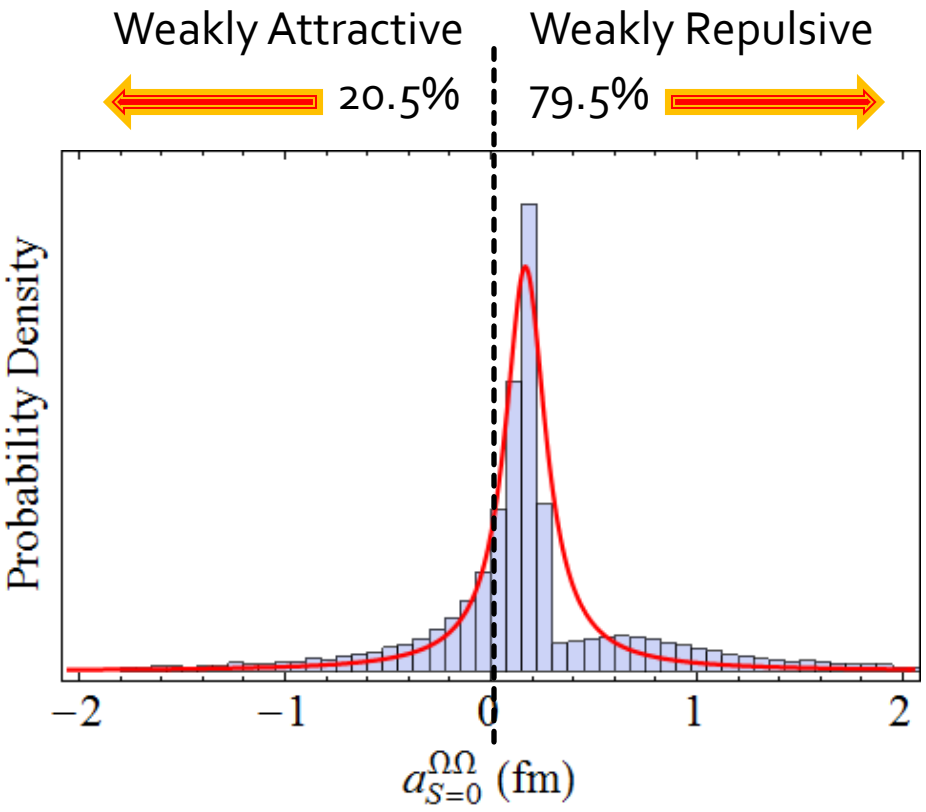
$$k \cdot \cot \delta(k) = \frac{1}{\pi L} S\left(\frac{k^2 L^2}{4\pi^2}\right) = -\frac{1}{a} + \tfrac{1}{2} r k^2 + \ldots.$$

$$S(\eta) = \sum_{\vec{j} \neq 0}^{\Lambda} \frac{1}{j^2 - \eta} - 4\pi\Lambda$$

A_1^+ Scattering



A_1^+ Scattering



- 10k random pairs from kcotδ distributions
- Fit to effective range expansion
- *r* distribution absorbs higher orders
- *a* distribution is Lorentzian

$$a_{S=0}^{\Omega\Omega} = 0.16 \pm 0.22 \text{ fm}$$

Conclusions

- Scattering length & k^2 values indicate a weakly repulsive system.
- $a_{S=0}^{\Omega\Omega} = 0.16 \pm 0.22\,\mathrm{fm}$ at m_π~390 MeV
- Light quark dependence expected to be small, but needs to be checked.
- Contrast with other lattice hyperon results that are bound states.
  - May just reflect smaller influence of light quark dynamics
- **Phys. Rev. D85 (2012) 094511**
  - arXiv:1201.3596 [hep-lat]