Scale setting from precise Omega baryons

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Dublin,
5. June, 2024

What did we do and why?

R.J.Hudpsith, Matthias Lutz, DM, arXiv:2404.02769

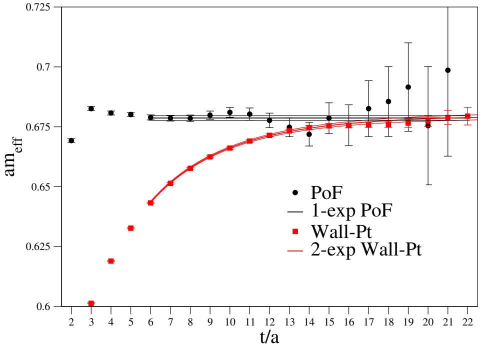
- Precise determination of $I(J^P) = 0(3/2)^+$ and $= 0(3/2)^-$ Ω-baryon ground states on $\mathrm{Tr}(M) = const.$ CLS ensembles.
- Description with $\mathrm{N}^3\mathrm{LO}$ $\mathrm{SU}(3)_f$ chiral perturbation theory
- Approach used for scale-setting and for determining $\sqrt{t_0}$.

Why the Ω-baryon?

- Known very precisely from experiment
- M_Ω is relatively straight-forward to determine with high precision (using a combination of standard spectroscopy methods)
- The strange-quark propagators are relatively cheap; no large noise to signal ratio
- No complicated improved currents and renormalization
- QCD stable state; strong isospin-breaking effects expected to be negligible; QED effects expected to be small;

Spectroscopy approach and methods

- Truncated solver method
- Gauge-fixed wall sources (wall-point correlators) for a better volume average
- GEVP with a simple 2×2 generalized Pencil of Functions matrix (see also Gregorio's talk)



SU(3) chiral fits

Our rewrite in terms of dimensionless quantities ($\varphi_Q = \tilde{m}_Q^2 = 8t_0 m_Q^2$, etc.)

$$\begin{aligned}
\frac{aM_\Omega^{\text{Latt.}}}{M_\Omega^{\text{Phys.}}} = \; & a\Big\{1 - 4\,(\tilde{d}_0 + \tilde{d}_D/3)\Delta(\tilde{m}_K^2 + \tilde{m}_\pi^2/2) - \frac{8}{3}\,\tilde{d}_D\,\Delta[\tilde{m}_K^2 - \tilde{m}_\pi^2] \\
& + \frac{1}{\tilde{f}^2}\,\tilde{c}_\Omega^2\,\Delta[\tilde{J}_{K\Xi}(\tilde{M}_\Omega)/Z_\Omega] + \frac{1}{3\,\tilde{f}^2}\,\tilde{h}_\Omega^2\,\Delta[\tilde{J}_{\eta\Omega}(\tilde{M}_\Omega)/Z_\Omega] + \frac{1}{3\,\tilde{f}^2}\,\tilde{h}_\Omega^2\,\Delta[\tilde{J}_{K\Xi^*}(\tilde{M}_\Omega)/Z_\Omega] \\
& - \frac{1}{\tilde{f}^2}\sum_{Q=\pi,K,\eta}\Big(\tilde{g}_{\Omega Q}^{(S)}\,\Delta[\tilde{m}_Q^2\,\tilde{I}_Q^{(0)}] + \tilde{g}_{\Omega Q}^{(V)}\,\Delta[\tilde{I}_Q^{(2)}]\Big) \\
& + \tilde{e}_\Omega^{(\pi)}\,\Delta[\tilde{m}_\pi^4] + \tilde{e}_\Omega^{(K)}\,\Delta[\tilde{m}_K^4] + \tilde{e}_\Omega^{(\eta)}\,\Delta[(\tilde{m}_K^2 - \tilde{m}_\pi^2)\,(4\,\tilde{m}_K^2 - \tilde{m}_\pi^2)/3]\Big\},
\end{aligned}$$

- $\Delta[\cdots]$ indicates subtraction by corresponding physical-point expression
- Promoting the physical t_0 in the subtractions to a fit parameter provides a t_0 determination

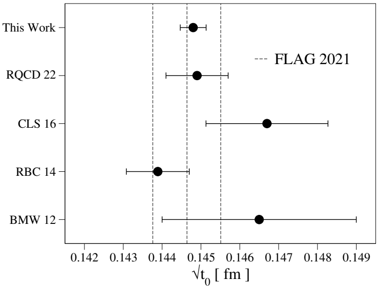
Results

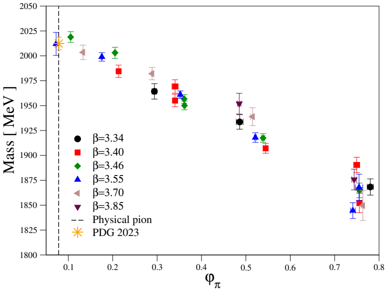
- We need N^{3}LO for a good fit.

LO	NLO	N^{2}LO	N^{3}LO (no $\tilde{g}^{(S/V)}_{\Omega\eta}$)	N^{3}LO (no $\tilde{g}^{(S/V)}_{\Omega(\pi/\eta)}$)
323	4.1	3.1	0.54	0.69

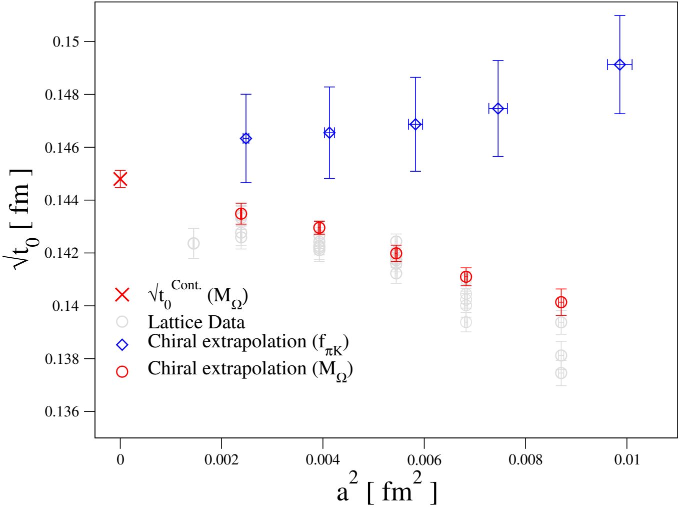
- Observed volume effects are dominated by $m_{K/\eta}L$.
- Resulting lattice spacings with relative uncertainties of $0.17\% \ldots 0.32\%$.
- Determination of t_0

$$\sqrt{t_0} = 0.14480(32)_{\text{Stat.}}(6)_{\text{QED}}(7)_{\text{Cuts}}\ \text{fm}\,.$$



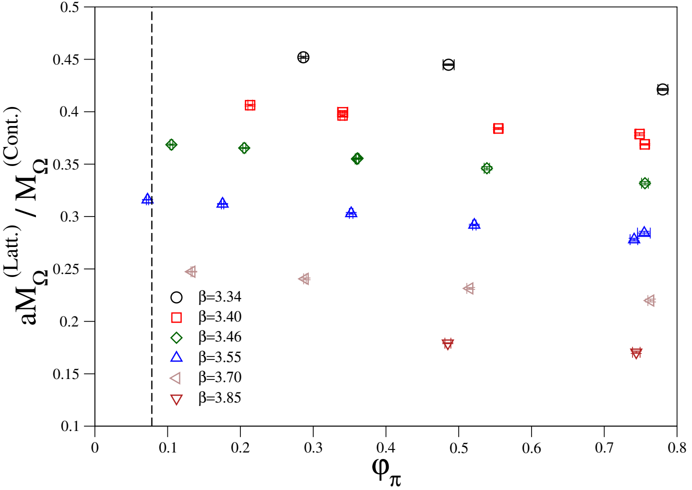


Cross-check: Cutoff dependence in $\sqrt{t_0}$

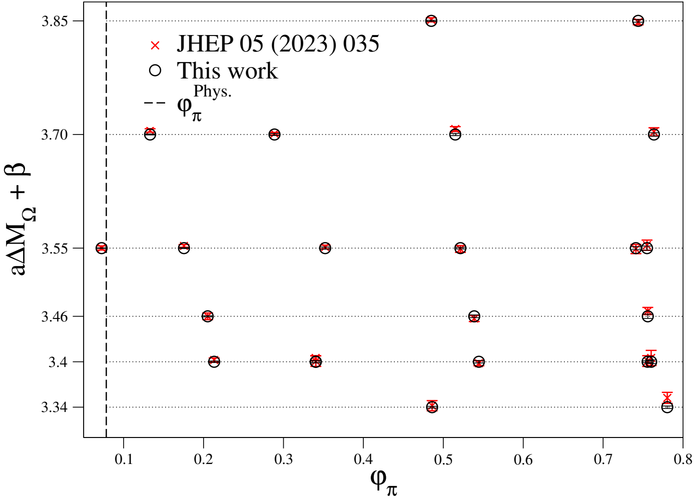


Backup slides

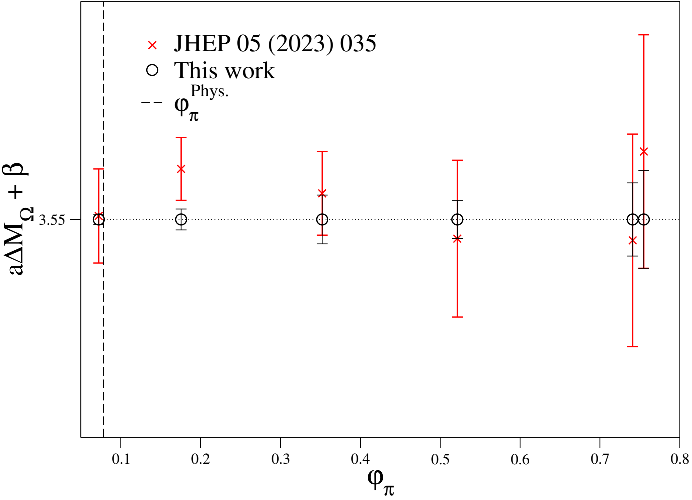
Data for our fits



Comparing our masses to the RQCD results I



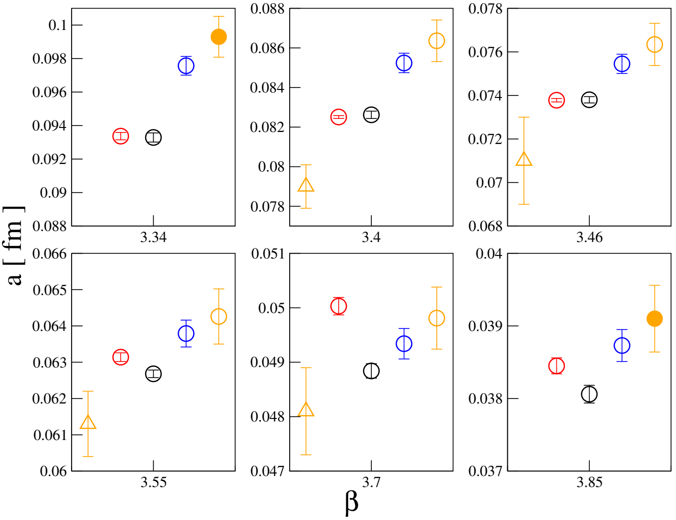
Comparing our masses to the RQCD results II



Chiral parameter and resulting lattice scales

f [MeV]	92.4	μ [MeV]	770
M [MeV]	804.3	$M + \Delta$ [MeV]	1115.2
$a(\beta = 3.34)$	$0.09329(27)(5)$ fm	$a(\beta = 3.40)$	$0.08262(18)(4)$ fm
$a(\beta = 3.46)$	$0.07380(14)(4)$ fm	$a(\beta = 3.55)$	$0.06268(10)(3)$ fm
$a(\beta = 3.70)$	$0.04884(13)(3)$ fm	$a(\beta = 3.85)$	$0.03806(12)(2)$ fm
d_0	$-0.39(13)$ GeV^{-1}	d_D	$-0.51(15)$ GeV^{-1}
C_A	$1.7(4)$	H_A	$0.6(2)$
$g_{\Omega K}^{(S)}$	$-13(4)$ GeV^{-1}	$g_{\Omega K}^{(V)}$	$48(12)$ GeV^{-1}
$e_{\Omega}^{(\eta)}$	$-0.13(4)$ GeV^{-3}	$\sqrt{t_0}$	$0.14480(32)(6)$ fm

Comparison to other CLS results



Effective masses on E250