Coupled channel scattering on the lattice: the $\Xi(1620)$ & $\Xi(1690)$

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Particle	J^P	Overall status
$\Xi(1320)$	$1/2+$	****
$\Xi(1530)$	$3/2+$	****
$\Xi(1620)$		**
$\Xi(1690)$	$1/2-$	***
$\Xi(1820)$	$3/2-$	****
$\Xi(1950)$		***
$\Xi(2030)$		***
$\Xi(2120)$		*
$\Xi(2250)$		**
$\Xi(2370)$		**
$\Xi(2500)$		*

We are in the **baryon resonances** conference...

- But resonances are not fundamental, why would they be relevant?

  $1/2^+$: $N(1440)$, $\Lambda(1600)$, ...

  $1/2^-$: $\Lambda(1405)$, $N(1535)$, ...

  $3/2^+$: $\Delta(1232)$, $\Sigma(1385)$, ...

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- Provide insight into QCD
  - Ω^- confirmed $SU(3)$ flavour symmetry
  - Δ^{++} lead to the postulation of color
  - teach us about symmetries and dynamics
  - low lying resonances are crucial in many observables, including weak processes

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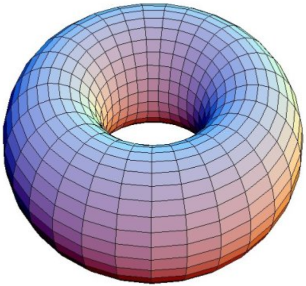
- Meson-baryon scattering
  - First way to study baryon excitations (since $\Delta(1232)$ in the ’50s)
  - Approachable from first principles on the lattice with Lüscher method
  - We present preliminary results on $\pi\Xi - \bar{K}\Lambda - \bar{K}\Sigma$ channels and the $\Xi(1620)$ and $\Xi(1690)$ resonances in the lattice

Meson-baryon scattering on the lattice

Lattice QCD approach

- Scattering in a finite volume thanks to Lüscher method [NPB,354(1991)][NPB,364(1991)]
- Necessity of multi-hadron operators already clear in meson-meson, otherwise the E spectrum is not resolved at t_f , e.g. [Wilson et al PRD 92 (2015)]



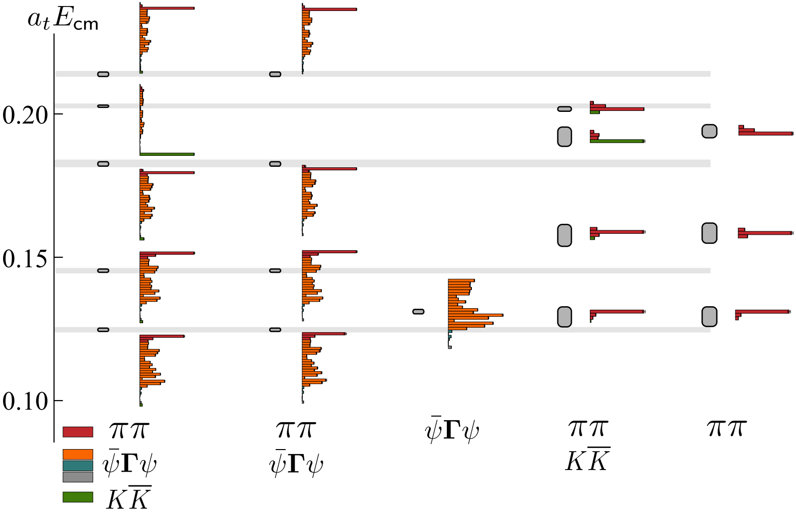


Figure 1: Spectrum with meson($\vec{p}$)meson($\vec{p}\,'$) ops ($I(J^P) = 1(1)^-$, $M_\pi \simeq 236$ MeV)[Wilson et al PRD 92 094502 (2015)].

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- Scattering in a finite volume thanks to Lüscher method

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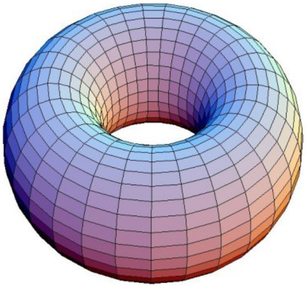
- Necessity of multi-hadron operators already clear in meson-meson, otherwise the E spectrum is not resolved , e.g. [Mohler et al PRD 87 (2013), Wilson et al PRD 92 (2015)]

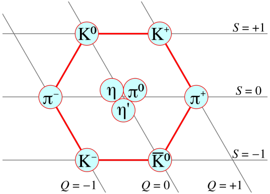
- $H(\vec{p})H(\vec{p}') \Rightarrow$ no translation invariance $\Rightarrow$ one computes at all $\vec{x}$
- Laplacian-Heaviside smearing:
  - smearing increases overlap with lower lying states
  - LapH reduces the size of the problem by considering only lower eigenstates of the Laplacian (quark perambulators can be stored)

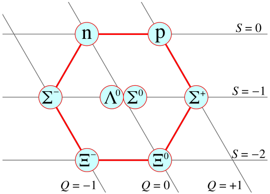
    [Peardon et al PRD 80 (2009)]

  - Optimised tensor contractions [PRL 123 (2019) 14, 142002]
- Pioneering meson-baryon works on πN
  - $N(1535)$ [Lang & Verduci PRD 87 (2013)]
  - $N(1440)$ [Lang et al PRD 95(2017)]
  - $\Delta(1232)$ [Alexandrou et al PRD 96 (2017), Bulava et al NPB 987 (2023)]



Negative parity hyperons from coupled channel scattering





Meson-baryon scattering

- Meson-baryon scattering in s-wave $\Rightarrow J^P = 1/2^-$:
  N^*, Λ^*, Σ^*, Ξ^*
- strangeness improves the signal
- $\Lambda(1405)$
  - Past works have studied the $\Lambda(1405)$ only with single-hadron operators [Nemoto PRD 68 (2003) 094505, Burch PRD 74 (2006) 014504, Takahashi PRD 81 (2010) 034505, Menadue PRL 108 (2012) 112001, Engel PRD 87(2013), 034502 & 034504, Hall PRL 114 (2015), Gubler PRD 94 (2016) 114518]
  - The $\Lambda(1405)$ study of BaSc employs two-hadron operators [Bulava et al PRL 132 (2024), Bulava et al PRD 109 (2024)]
- Ξ^* channel (preliminary results)

$\pi\Sigma - \bar{K}N$ and the $\Lambda(1405)$ resonance

Lüscher method

- $\det\left[\tilde{K}^{-1}(E) - B^{\mathsf{P}}(E)\right] = 0$

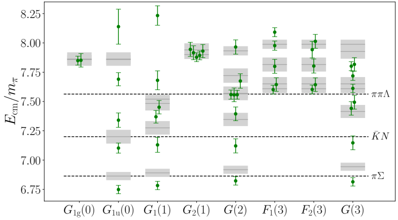
Amplitude analysis

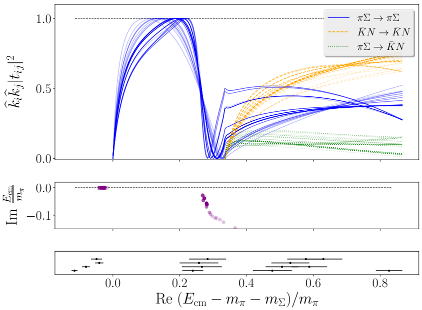
- five $\tilde{K}_{ij}$ parametrisations, $t^{-1} = \tilde{K}^{-1} - i\hat{k}$

Two poles extracted

(at $a \simeq 0.064$ fm, $m_\pi \simeq 200$ MeV, $m_K \simeq 480$ MeV)

1. virtual state:
   $E_1 = 1392(9)_{\rm st}(2)_{\rm md}(16)_{\rm sc}$ MeV
2. resonance pole:
   $E_2 = [1455(13)_{\rm st}(2)_{\rm md}(17)_{\rm sc} - i\ 11.5(4.4)_{\rm st}(4)_{\rm md}(0.1)_{\rm sc}]$ MeV

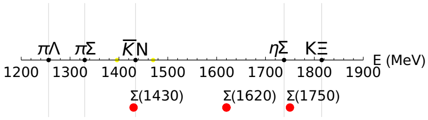




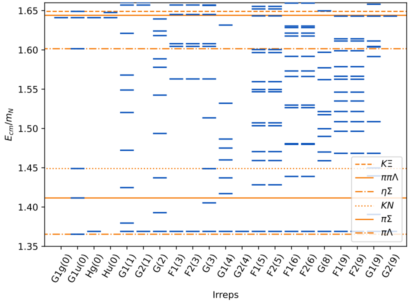
Σ flavour channel

lattice results in this sector are highly desired [Pittler et al PRD 112 (2025)]

- $\Sigma(1430)$ is getting a lot of attention
  - A structure compatible with $\Sigma(1430)$ was recently observed by Belle in in $\Lambda_c^+ \to \Lambda\pi^+\pi^-\pi^-$ [PRL 130, 151903 (2023)]
  - predicted by $\sim$UChPT , [Kaiseret al NPA 594 (1995) 325], [Oset, Ramos, NPA 635 (1998) 99], [Jido et al NPA 725 (2003) 181] [Oller & Meissner PLB 500 (2001)]
  - Wei-Hong Liang studied it with correlation fcns on Monday: [PRD 110 (2024) 114018] [EPJC 85 (2025) 1086]
  - Low support for qqq [Lin et al PRD 112 (2025) 1, 014044]



- $\Sigma(1430)$
  - We have set up the calculation to study $\pi\Lambda$, $\pi\Sigma$, $\bar{K}N$
  - Chosen ensemble: X451, $M_\pi \simeq 287$ MeV



$\pi\Xi - \bar{K}\Lambda - \bar{K}\Sigma$ channels and the $\Xi(1620)$ and $\Xi(1690)$ resonances

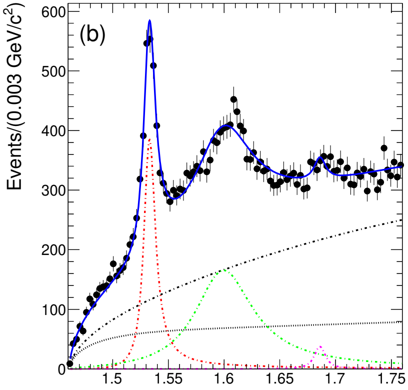


Figure 2: Events vs $M_{\Xi^-\pi^+}$ (GeV/c^2) ($\Xi(1530) + \Xi(1620) + \Xi(1690)$) from Belle $\Xi_c \to \Xi\pi\pi$ [Sumihama et al PRL (2019)].

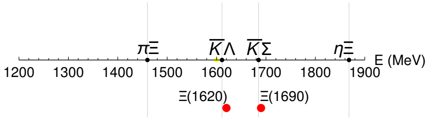
$\Xi(1620)$ & $\Xi(1690)$, *a stranger counterpart of the* $\Lambda(1405)$

(**) & (***) on PDG

- Recent experimental results support both states
  - Belle $\Xi_c \to \Xi\pi\pi$
    $m = 1610.4 \pm 6.0^{+5.9}_{-3.5}$ MeV, $\Gamma = 59.9 \pm 4.8^{+2.8}_{-3.0}$ MeV
    [Sumihama PRL (2019)]
  - LHCb $\Xi_b \to J/\Psi\Lambda K$
    $m = 1692.0 \pm 1.3^{+1.2}_{-0.4}$, $\Gamma = 25.9 \pm 9.5^{+14.0}_{-13.5}$
    [Aaij, Sci. Bull. (2021)]
  - ALICE $\pi\Xi$ femtoscopy
    $m^0 = 1608.16 \pm 1.5$ MeV, $\Gamma^0 = 47.12 \pm 5.63$ MeV;
    $m^0 = 1680.72 \pm 3.27$ MeV, $\Gamma^0 = 26.41 \pm 13.86$ MeV
    [Abualrob, PLB (2026)]

Ξ flavour channel

- $\Xi(1620)$ & $\Xi(1690)$
  - UChPT (Weinberg-Tomozawa) model, e.g. [Ramos, Oset & Bennhold, PRL 89 (2002)] & [García-Recio, Lutz & Nieves, PLB 582 (2004)]
    - [Li et al EPJC 83 (2023) 10, 95] see two poles in $\Xi_c \to \Xi\pi\pi$
    - NLO UChPT model [Feijoo et al PLB 841 (2023)]
  - modelling CF in femtoscopy
    - [Mantovani et al PRD 110 (2024)] argues that it is mostly $\eta\Xi$ in contrast with previous literature
    - Consistency problem when comparing processes [Feijoo et al PRD 111 (2025) 1, 014022] [Veloso, Khemchandani et al., arXiv:2608.27736]



- Different approaches do not lead to a clear agreement, different $m_R, \Gamma_R, |g_{ij}|$ and number of poles.

CLS ensembles

Lattice setup: a pathway through CLS ensembles

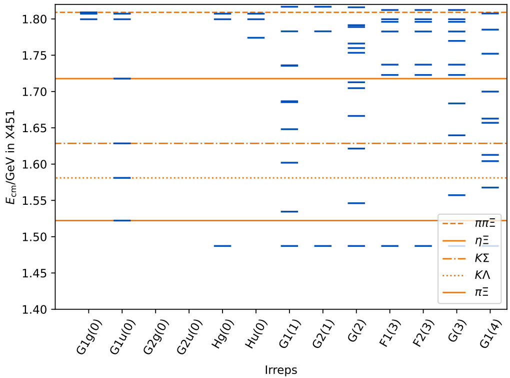
joint effort of the **BaSc** collaboration

(= tree-level improved Lüscher-Weisz gluons and nonperturbatively $\mathcal{O}(a)$ improved Wilson fermions)

ensembles	boundary	a	$T \times L^3$	m_π	m_K	$m_\pi L$	N_{cnfg}
D200	open	0.064 fm	128×64^3	200 MeV	480 MeV	4.3	2000
X451	periodic (better sampling)	0.075 fm	" $\times\, 40^3$	287 MeV	464 MeV	4.4	2000
N451	"	"	" $\times\, 48^3$	"	"	5.3	1000
E250	"	0.064 fm	192×96^3	131 MeV	493 MeV	4.1	1000

- We have computed the $\Xi(1/2^-)$ correlators on X451 (up to few remaining configs)
- We will also calculate them on N451: X451 & N451 only differ in volume $\Rightarrow$ constrain more E_{cm}

- Ξ channel expected free levels in X451 and N451



J^P	[000]	[00n]	[0nn]	[nnn]	
$1/2^+$	G_{1g}	G_1	G	G	Ξ
$1/2^-$	G_{1u}	G_1	G	G	$\Xi(1620)$, $\Xi(1690)$
$3/2^+$	H_g	G_1, G_2	$2G$	F_1, F_2, G	$\Xi(1530)$
$3/2^-$	H_u	G_1, G_2	$2G$	F_1, F_2, G	$\Xi(1820)$

$G_{1u} \simeq 1/2^-$ (only contaminated by $\ell = 4$)

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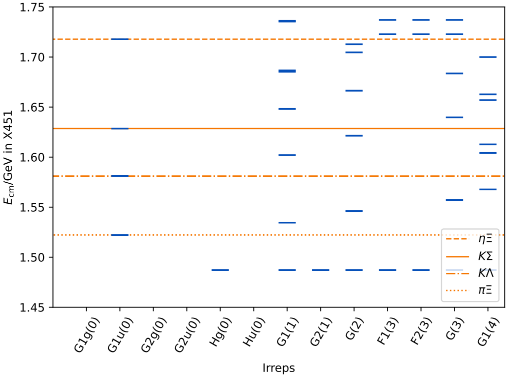

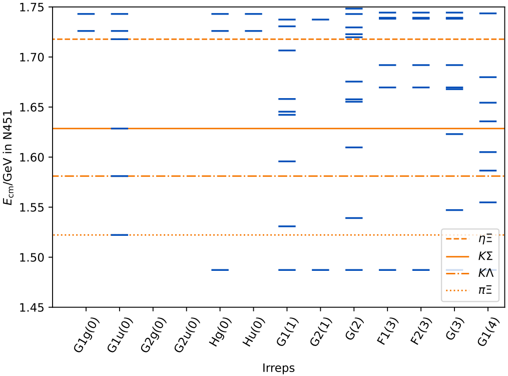

J^P	[000]	[00n]	[0nn]	[nnn]	
$1/2^+$	G_{1g}	G_1	G	G	Ξ
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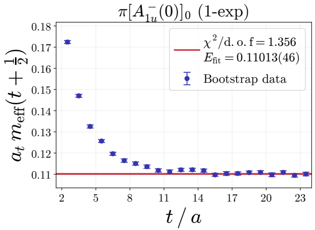
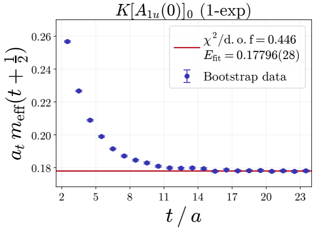
$3/2^+$	H_g	G_1, G_2	$2G$	F_1, F_2, G	$\Xi(1530)$
$3/2^-$	H_u	G_1, G_2	$2G$	F_1, F_2, G	$\Xi(1820)$

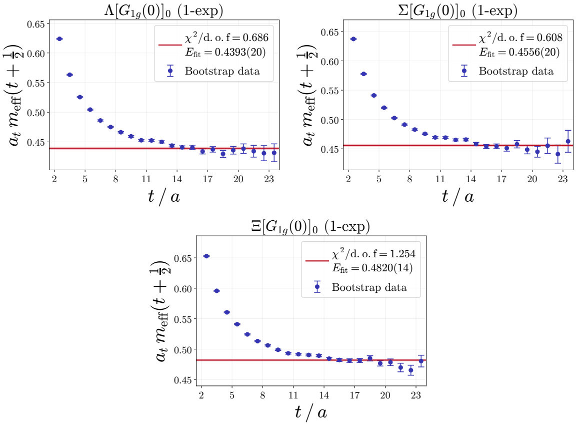
$G_{1u} \simeq 1/2^-$ (only contaminated by $\ell = 4$)

Production on X451:

- in Figs.: single hadron m_{eff} on 1683/2026 configs, one source and direction (from tot four, 1683/8104 meas)







Production on X451:

- in Figs.: single hadron m_{eff} on 1683/2026 configs, one source and direction (from tot four, 1683/8104 meas)
- periodic boundary conditions and source time varied randomly: reduce baryon noise
- double strangeness should improve signal with respect to Λ channel
  - absence of nucleons reduces the baryon noise further
- consistency with expectations and $\sim$ ideal scaling
- $m_\pi \simeq 286$ MeV, $m_K \simeq 462$ MeV, $m_\Lambda \simeq 1141$ MeV, $m_\Sigma \simeq 1183$ MeV, $m_\Xi \simeq 1255$ MeV

- 3161(/8000) meas. in 1592(/2026) cfg.
- $\pi\Xi - \bar{K}\Lambda - \bar{K}\Sigma$ operators + all local 3-quarks operators
- GEVP with 9/8 operators

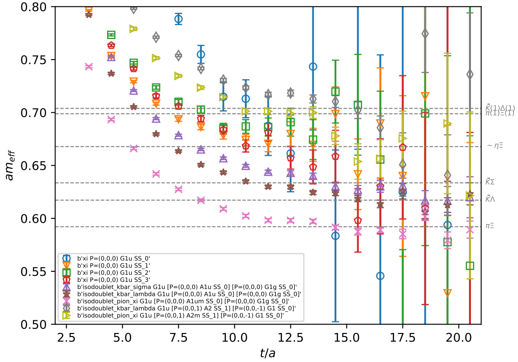


Figure 3: Effective masses of the 9 G1u ops.

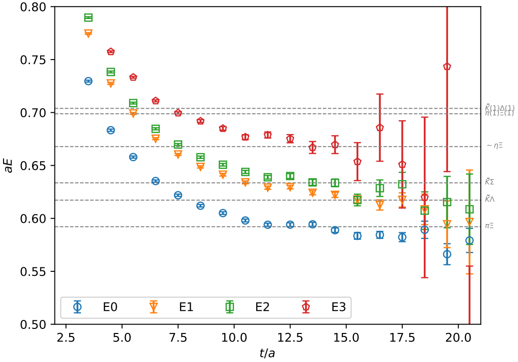
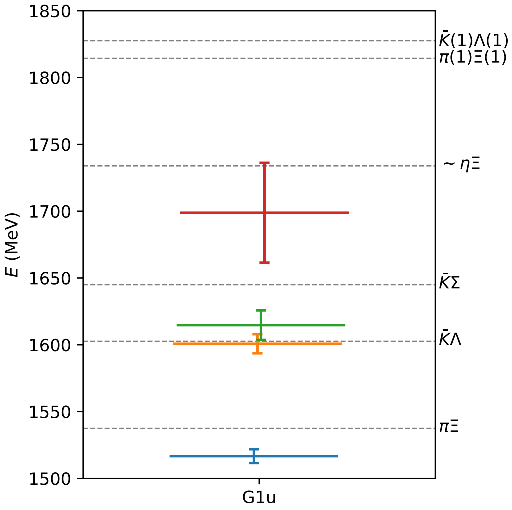


Figure 4: GEVP E_{0-4}.



- Fits with $\chi_i^2/\mathrm{dof} \simeq 1$
- In the physical world $\eta\Xi$ opens ~ 1870 MeV, significantly higher than $\Xi(1620)$, $\Xi(1690)$.
- moderate $\pi\Xi$ attraction, $\Delta E_{\pi\Xi} = 21 \pm 6$ MeV
  - consistent with expectations from the continuum

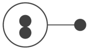
Displaced Operators

Displaced Operators

- We are studying displaced operators in order to improve the description of hadrons in general

SS: $\epsilon_{abc}\tilde{\psi}^{A}_{a\alpha}\tilde{\psi}^{B}_{b\beta}\tilde{\psi}^{C}_{c\gamma}$

SD: $\epsilon_{abc}\tilde{\psi}^{A}_{a\alpha}\tilde{\psi}^{B}_{b\beta}\left(\tilde{D}^{(p)}_{j}\tilde{\psi}\right)^{C}_{c\gamma}$



  - We have started studying Λ ops. on X451
    - displaced ops. should help to disentangle states
    - drawback: noisier than local ones
  - theoretical input is beneficial: $\Lambda(1520)$ case

- **Displaced operators: $\Lambda(1520)$**, a $J^P = \frac{3}{2}^-$ state
  - $\sim$UChPT meson-decuplet scatt. [Kolomeitsev & Lutz PLB 585 (2004)]
  - quark model: $L = 1$, $S = 1/2$, flav. singlet [Gromes ZPC 18 (1983)]

$$(O_{\Lambda^*})_{j\gamma} = \epsilon^{abc}(C\gamma_5)_{\alpha\beta}\left(\frac{1+\gamma_0}{2}\right)_{\gamma\delta}[\tilde{s}^a_\alpha \tilde{d}^b_\beta (\tilde{\nabla}_j \tilde{u})^c_\delta - \tilde{s}^a_\alpha \tilde{u}^b_\beta (\tilde{\nabla}_j \tilde{d})^c_\delta + \tilde{u}^a_\alpha (\tilde{\nabla}_j \tilde{d})^b_\beta \tilde{s}^c_\delta - \tilde{d}^a_\alpha (\tilde{\nabla}_j \tilde{u})^b_\beta \tilde{s}^c_\delta]$$

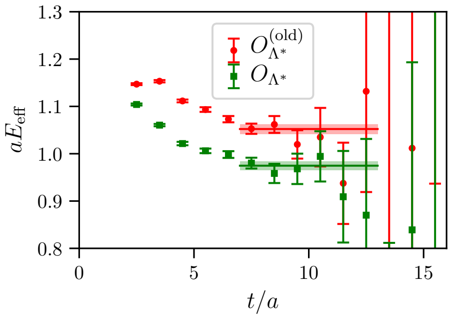


Figure 5: $\Lambda(1520)$ from [Meinel et al. PRD 103 (2021) 074505]

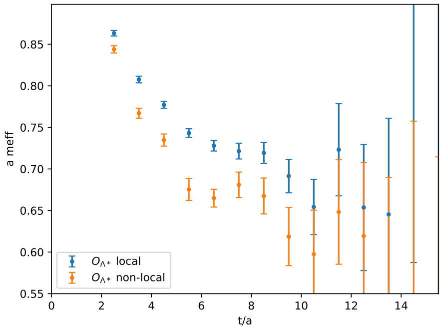


Figure 6: $\Lambda(1520)$ on X451

Conclusions and Outlook:

- A comprehensive set of single- and multi-hadron operators is indispensable to study scattering
- $\Xi(1620)$ & $\Xi(1690)$ constitute a challenging $\pi\Xi - \bar{K}\Lambda - \bar{K}\Sigma$ coupled channel problem
- S-wave and double strangeness make it a good target for LQCD, we attack it first on X451
- This and other ensembles are expected to provide a robust amplitude parametrization and extrapolation to the physical world
- preliminary results show moderate $\pi\Xi$ attraction from first principles
- Displaced operators are expected to be beneficial in several analyses

Appendix I

Using the above definition, it is straightforward to show that the unitarity of S implies the Hermiticity of K. Time reversal invariance of the S-matrix implies that the K-matrix must be symmetric. Given its Hermiticity, this means that K is real and symmetric. Rotational invariance implies that the K-matrix must have the form

- $t^{-1} = \tilde{K}^{-1} - i\hat{k}$, with $m_\pi \hat{k} = \text{diag}\ (k_{\pi\Sigma}, k_{\bar{K}N})$ and $\tilde{K}$ hermitic due to unitarity
- $\det[\widetilde{K}^{-1}(E_{\text{cm}}) - B^P(E_{\text{cm}})] + \mathrm{O}(\mathrm{e}^{-ML}) = 0$
- $\langle J' m'_J \ell' S' a' | K | J m_J \ell S a \rangle = \delta_{J'J} \delta_{m'_J m_J} K^{(J)}_{\ell' S' a'; \ell S a}(E_{\text{cm}})$
- all models with $\text{AIC} - \text{AIC}_{\text{min}} < 1$, and taking half the difference in the maximal spread of values as the model uncertainty. In future work, when a full extrapolation to the physical point is performed, a more thorough determination of the model-average and systematic uncertainty will be performed.
- AIC_{min} for ERE (and $\chi^2/\text{dof} = 10.52/11$), values
  - ERE: $\tilde{K}_{ij} = \frac{m_\pi}{E_{cm}}(A_{ij} + B_{ij}\Delta(E_{cm}))$, with $\Delta(E_{cm}) = (E_c m^2 - (m_\pi + m_\Sigma)^2)/(m_\pi + m_\Sigma)^2$

Appendix II

- link variables are stout smeared, $\rho = 0.1$, $n_\rho = 36$
- An advantage feature of LapH is source-sink factorization of the correlators which greatly facilitates the evaluation of large Hermitian correlation matrices via optimized tensor contractions
- Low-lying eigenvalues of the Dirac matrix of either the light quark doublet or the strange quark can cause instabilities in the HMC an issue which is sufficiently ameliorated by light- and strange-quark reweighting.
- relative quark lines only at the sink

D200

- $N_{\rm ev} = 448$
- $N_{\rm bin} = 10$, jackknife and bootstrap ($N_B = 800$)
- single-pivot with $t_0 = 4a$ and $t_{\rm diag} = 16a$
  - $t^{-1} = \tilde{K}^{-1} - i\hat{k}$
  - $\det[\widetilde{K}^{-1}(E_{\rm cm}) - B^P(E_{\rm cm})] + \mathrm{O}(\mathrm{e}^{-ML}) = 0$
  - several $\tilde{K}_{ij}$ parametrisations (ERE, ERE of $\tilde{K}_{ij}^{-1}$, Blatt-Biederharn, W-T inspired, lin. around $\pi\Sigma_{\rm thr}$)
- sixteen energies are used, which include the fifteen energies from the s-wave fits and one G1g(0) level, and we incorporate a 1/2+ wave in the K-matrix parametrization. In the second additional fit, seventeen energies are used, which include the fifteen energies from the s-wave fits and one level each in the F1(2), F2(3) irreps, and we add a 3/2+ wave in the K-matrix parametrization.
- coupling from residues of poles 1 and 2:
  $\left|\frac{c^{(1)}_{\pi\Sigma}}{c^{(1)}_{\bar{K}N}}\right| = 1.9(4)_{\mathsf{st}}(6)_{\mathsf{md}}$, $\left|\frac{c^{(2)}_{\pi\Sigma}}{c^{(2)}_{\bar{K}N}}\right| = 0.53(9)_{\mathsf{st}}(10)_{\mathsf{md}}$

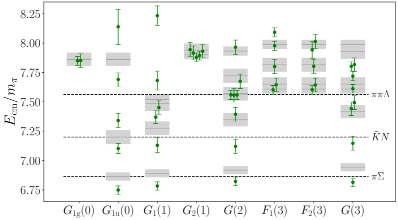
Appendix III

X451

- $N_{\mathrm{ev}} = 180$
- 3 coupled ch $\sim$ 6 functions in general

Appendix IV

Single- & two-hadron ops. are necessary to extract levels:
$\Lambda[G_{1u}(0)]_0$
$\Lambda[G_{1u}(0)]_1$
$\Lambda[G_{1u}(0)]_2$
$\Lambda[G_{1u}(0)]_3$
$\bar{K}[A_{1u}(0)]_0\ N[G_{1g}(0)]_0$
$\pi[A_{1u}^{-}(0)]_0\ \Sigma[G_{1g}(0)]_0$
$\bar{K}[A_2(1)]_1\ N[G_1(1)]_0$
$\pi[A_2^{-}(1)]_1\ \Sigma[G_1(1)]_0$



D200 extracted E levels

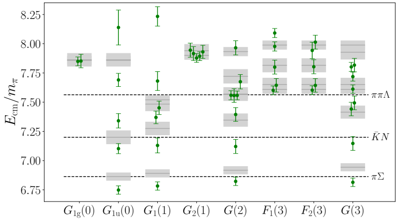
Rest Frame Irreps

J^P	[000]	[00n]	[0nn]	[nnn]	
$1/2^+$	G_{1g}	G_1	G	G	Λ, $\Lambda(1600)$
$1/2^-$	G_{1u}	G_1	G	G	$\Lambda(1405)$, $\Lambda(1670)$
$3/2^+$	H_g	G_1, G_2	$2G$	F_1, F_2, G	-
$3/2^-$	H_u	G_1, G_2	$2G$	F_1, F_2, G	$\Lambda(1520)$, $\Lambda(1690)$

- $G_{1u} \simeq 1/2^-$ (only contaminated by $\ell = 4$)
- moving frames: mixing of quantum numbers (more operators)
  - $J^P = 1/2^+, 3/2^+$ contamination seems negligible close to lowest threshold, but more data will improve analysis

Appendix V

- Correlation matrix
  - $C_{ij}(t) = \langle \mathcal{O}_i(t)\bar{\mathcal{O}}_j(0)\rangle = \sum_k A_k^{(ij)} e^{-tE_k}$
  - Stochastic Laplacian Heaviside distillation [Peardon et al PRD 80 (2009)], [Morningstar et al PRD 83 (2011)]
    - source-sink factorization allows to use optimised tensor contractions to evaluate correlation matrices containing large sets of multi-hadron ops
    - only low modes of the Laplacian are kept (smearing) (quark perambulators can be stored)



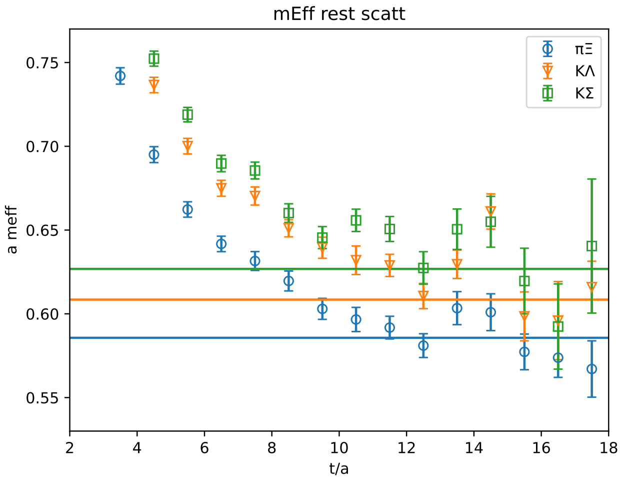
D200 extracted E levels

- GEVP (increases ΔE_{eff}) and ratio fits to extract lowest lying E_k from earlier plateaus
  - $C(t)\,\vec{v} = \lambda(t)\,C(t_0)\,\vec{v}$

Appendix VI

Production on X451:

- three coupled channels
  $\mathcal{O}(50\mathrm{MeV})$ separation
- 135 cnfgs on one source and direction ($\sim$1% data)
  - consistent with noninteracting thresholds



Appendix VII

- Single hadron operators in the $J^P = 1/2^-$ channel

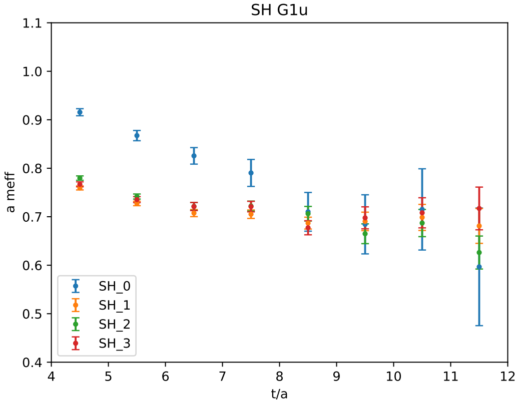


Figure 7: before GEVP

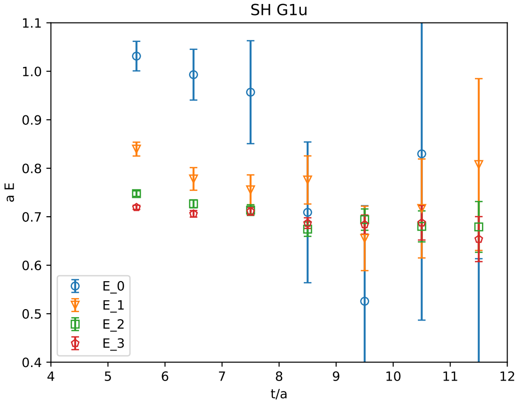
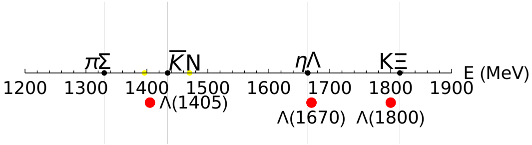


Figure 8: after GEVP

$\Lambda(1405)$ channel

- '60s-'80s bubble chamber exps. $K^- p$ [Alston et al PRL 6 (1961) 698]
- $J^P = 1/2^-$ confirmed in $\gamma p \to K^+ \Lambda(1405)$ polarisation by CLAS [Moriya et al., PRC 87 035206 (2013)]
- $\Lambda(1405)$ (****) & $\Lambda(1380)$ (**)?



Negative parity hyperons from coupled channel scattering

Simplified illustration of m_q dep. of $\boldsymbol{\Lambda}\mathbf{(1405)}$

- SU(3): $8 \otimes 8 = 1 \oplus 8 \oplus 8 \oplus 10 \oplus \bar{10} \oplus 27$

Negative parity hyperons from coupled channel scattering

Simplified illustration of m_q dep. of $\boldsymbol{\Lambda(1405)}$

- SU(3): $8 \otimes 8 = 1 \oplus 8 \oplus 8 \oplus 10 \oplus \overline{10} \oplus 27$
- $\mathcal{L}_{\mathrm{WT}} \Longrightarrow$ only $1 \oplus 8 \oplus 8$ are attractive

Simplified illustration of m_q dep. of $\boldsymbol{\Lambda(1405)}$

- SU(3): $8 \otimes 8 = 1 \oplus 8 \oplus 8 \oplus 10 \oplus \bar{10} \oplus 27$
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- If one observes one pole with $I = 0$, then one could expect three isosinglets

Simplified illustration of m_q dep. of $\boldsymbol{\Lambda}$**(1405)**

- SU(3): $8 \otimes 8 = 1 \oplus 8 \oplus 8 \oplus 10 \oplus \overline{10} \oplus 27$
- $\mathcal{L}_{\mathrm{WT}} \Longrightarrow$ only $1 \oplus 8 \oplus 8$ are attractive
- If one observes one pole with $I = 0$, then one could expect three isosinglets
- $\sim$UChPT with SU(3) broken by m_q predicts only two poles arround 1400 MeV

  [Oller & Meissner PLB 500 (2001); Jido, Oller, Oset, Ramos, Meissner NPA 725 (2003)]

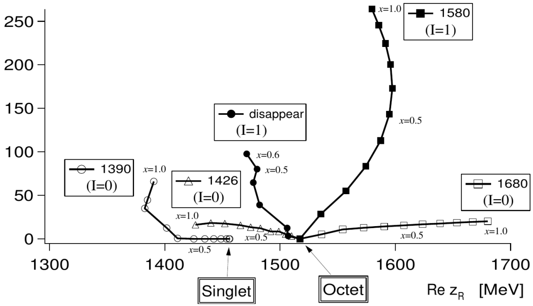

FIg. from [Jido, Oller, Oset, Ramos, Meissner NPA 725 (2003)]

Lattice setup: a pathway through CLS ensembles

joint effort of the **BaSc** collaboration

- $\Lambda(1405)$ already studied on D200 ($m_\pi = 200$ MeV) with CLS action [Bulava et al]

  (= tree-level improved Lüscher-Weisz gluons and nonperturbatively $\mathcal{O}(a)$ improved Wilson fermions)

- More ensembles under investigation

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   - connect SU(3) and phys point ⇒ theoretical insight and physical relevance

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- ⇒ Motivates current analysis on X451: $\neq m_q, a, L$ (and next N451)
  - $m_\mathrm{q}^\mathrm{phys}$ on E250 is on the horizon
- We also study Ξ channel on X451 (N451 next)

ensembles	boundary	a	$T \times L^3$	m_π	m_K	$m_\pi L$	N_cnfg
D200	open	0.064 fm	128×64^3	200 MeV	480 MeV	4.3	2000
X451	periodic (better sampling)	0.075 fm	" $\times 40^3$	287 MeV	464 MeV	4.4	2000
N451	"	"	" $\times 48^3$	"	"	5.3	1000
E250	"	0.064 fm	192×96^3	131 MeV	493 MeV	4.1	1000