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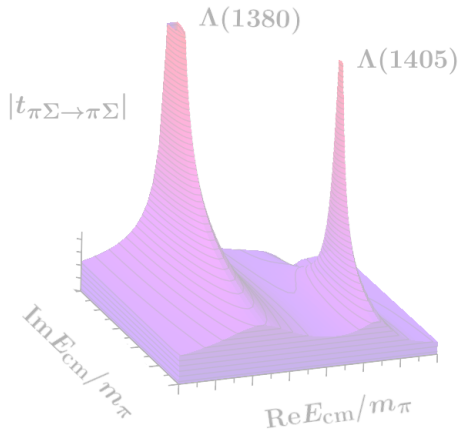
# Recent Lattice QCD studies of strange baryons

*15th International Workshop on the Physics  
of Excited Nucleons*  
Sevilla, España

**Bárbara Alexandra Cid-Mora**  
September 7th to 11th, 2026



- A bit of history:
  - The curious cases of the  $\Lambda$  and  $\Xi$  baryons
- Lattice QCD as a tool:
  - To explore coupled-channel dynamics
  - To study scattering amplitudes
- Extraction of finite-volume energy spectra
- The Lüscher formalism
- Summary and future plans



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- ⊙ Negative parity strange baryons
- ⊙ Lattice QCD
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- ⊙ Summary

### $\Lambda$ resonances

[PDG, PRD 110 (2024) 030001]

| Hadron          | $J^P$   | status |
|-----------------|---------|--------|
| $\Lambda$       | $1/2^+$ | (****) |
| $\Lambda(1380)$ | $1/2^-$ | (**)   |
| $\Lambda(1405)$ | $1/2^-$ | (****) |
| $\Lambda(1520)$ | $3/2^-$ | (****) |

$$\Lambda(1405) \rightarrow \pi \Sigma - \bar{K} N$$

✱ Two-pole structure

✱ Limited lattice coupled-channel studies

### $\Xi$ resonances

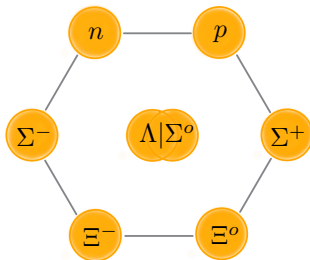
[PDG, PRD 110 (2024) 030001]

| Hadron      | $J^P$   | status |
|-------------|---------|--------|
| $\Xi^{0/-}$ | $1/2^+$ | (****) |
| $\Xi(1620)$ | $1/2^-$ | (**)   |
| $\Xi(1690)$ | $1/2^-$ | (***)  |

$$\Xi(1620)/\Xi(1690) \rightarrow \pi \Xi - \bar{K} \Sigma - \bar{K} \Lambda$$

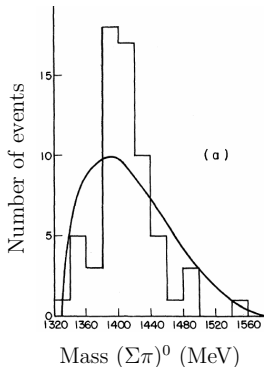
✱ Poorly constrained states

✱ No lattice coupled-channel studies



**Exotic nature:** dynamically generated meson–baryon resonances

$$\Lambda(1405) \rightarrow I(J^P) = 0(\frac{1}{2}^-) \quad S = -1$$



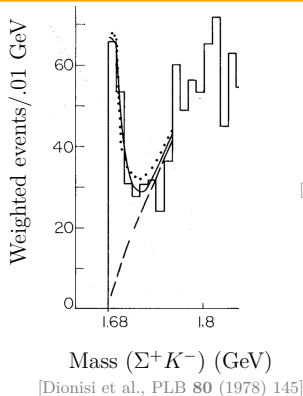
[Alston et al., PRL 6 (1961) 698]

- [PRL 2 (1959) 425] — Theoretical Prediction  $K^-p \rightarrow \pi\Sigma$
- [PRL 6 (1961) 698] — Experimental evidence of resonance ( $\pi\Sigma$  mass spectrum)
- [PLB 137 (1984) 415]  
[PLB 176 (1986) 229] — Meson-Baryon comp.  $\Lambda(1405)$  (Chiral sym.)
- [PRC 41 (1990) 2720] — First time two-pole picture
- [NPA 594 (1995) 325]  
[NPA 635 (1997) 99] — Chiral dynamics: coupled-channel
- [PLB 704 (2011) 113] — SIDDHARTA at DAΦNE:  $K^-p$  Scattering Length det.
- [PRC 87 (2013) 035206]  
[PRL 112 (2014) 082004] — Spin & Parity by CLAS Collab.
- [2024] — Coupled-channel lattice study (Two-pole structure)  
[PRD 109 (2024) 5] [PRL 132 (2024) 1]

# The strange $\Xi(1620)$ and $\Xi(1690)$

1 Negative parity strange baryons

$$\begin{matrix} \Xi(1690) \\ \Xi(1620) \end{matrix} \rightarrow I(J^P) = \frac{1}{2}(\frac{1}{2}^-) \quad S = -2$$



[PLB 80 (1978) 145-149]

Experimental evidence of resonance  
( $\Sigma K$  mass spectrum)

[EPJC 5 (1998) 621-624]

Confirmation of existence of  
resonant state

[PRL 89 (2002) 252001]

Chiral approach: dynamically  
generated

[PLB 582 (2004) 49-54]

[Aubert et al., (2006) hep-ex/0607043]

On their quantum numbers

[PRD 75 (2007) 074002]

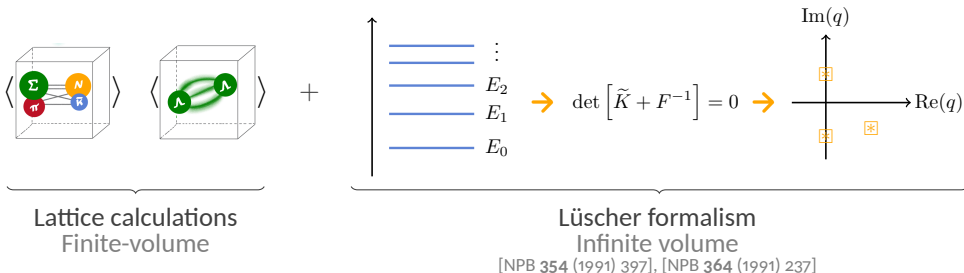
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[PRL 122.7 (2019) 072501]

Further confirmation of existence  
of resonance

[2026]

**No coupled-channel  
lattice study**

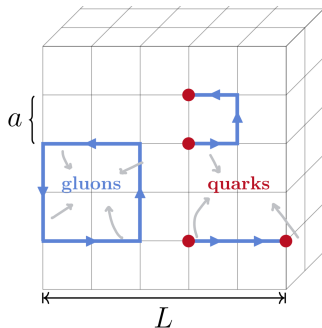


- ⊕ Finite-volume energy spectra encode scattering information
- ⊕ Controlled study of near-threshold dynamics and quark-mass dependence
- ⊕ Resulting motion of poles under variation of quark masses

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- Quarks and gluons in a finite discretized grid
- Observables estimated by sampling gauge configurations
- Correlation functions are computed according to the quantum numbers of interest
- Finite-volume energy spectrum extraction



$$C(t) = \langle \mathcal{O}_2(t_f) \overline{\mathcal{O}}_1(t_i) \rangle = \frac{1}{Z} \int \mathcal{D}[\psi, \overline{\psi}] \mathcal{D}[U] e^{-S_F[\psi, \overline{\psi}, U] - S_G[U]} \mathcal{O}_2[\psi, \overline{\psi}, U] \overline{\mathcal{O}}_1[\psi, \overline{\psi}, U]$$

### Interpolating operators $\mathcal{O}_i$

#### ► Single-hadron operators (SH)

$$\pi[\vec{\mathbf{d}}], \bar{K}[\vec{\mathbf{d}}], N[\vec{\mathbf{d}}]$$

$$\Lambda[\vec{\mathbf{d}}], \Sigma[\vec{\mathbf{d}}], \Xi[\vec{\mathbf{d}}]$$

#### ► Multi-hadron operators (MH)

$$\pi[\vec{\mathbf{d}}_1]\Sigma[\vec{\mathbf{d}}_2], \bar{K}[\vec{\mathbf{d}}_1]N[\vec{\mathbf{d}}_2]$$

$$\pi[\vec{\mathbf{d}}_1]\Xi[\vec{\mathbf{d}}_2], \bar{K}[\vec{\mathbf{d}}_1]\Lambda[\vec{\mathbf{d}}_2], \bar{K}[\vec{\mathbf{d}}_1]\Sigma[\vec{\mathbf{d}}_2]$$

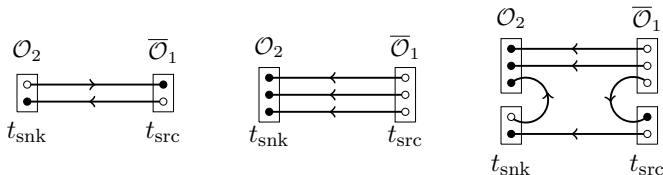
### Irreducible representations (irreps)

| $J^P$           | Irrep    | $\Lambda/\Xi$ -baryon          |
|-----------------|----------|--------------------------------|
| $\frac{1}{2}^+$ | $G_{1g}$ | $\Lambda, \Lambda(1600)$       |
| $\frac{1}{2}^-$ | $G_{1u}$ | $\Lambda(1405), \Lambda(1670)$ |
| $\frac{3}{2}^-$ | $H_u$    | $\Lambda(1520), \Lambda(1690)$ |
| $\frac{1}{2}^+$ | $G_{1g}$ | $\Xi$                          |
| $\frac{1}{2}^-$ | $G_{1u}$ | $\Xi(1620), \Xi(1690)$         |
| $\frac{3}{2}^-$ | $H_u$    | $\Xi(1820)$                    |

| Ensemble | a [fm] | $L^3 \times T$    | $m_\pi$                   | $m_K$                     | BC       | $N_{\text{cfgs}}$ |
|----------|--------|-------------------|---------------------------|---------------------------|----------|-------------------|
| D200     | 0.0633 | $64^3 \times 128$ | $\approx 200 \text{ MeV}$ | $\approx 487 \text{ MeV}$ | Open     | 2000              |
| X451     | 0.0761 | $40^3 \times 128$ | $\approx 280 \text{ MeV}$ | $\approx 465 \text{ MeV}$ | Periodic | 2026              |

### ► Correlation matrices → Stochastic LapH method (sLapH)

[PRD 80 (2009) 054506] (Original distillation), [PRD 83 (2011) 114505]



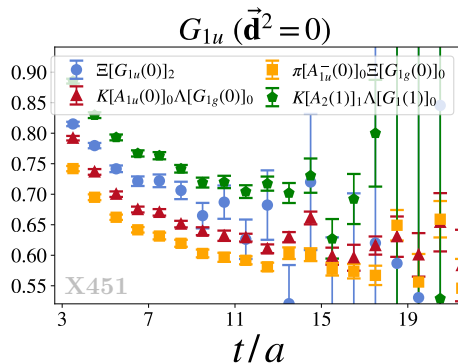
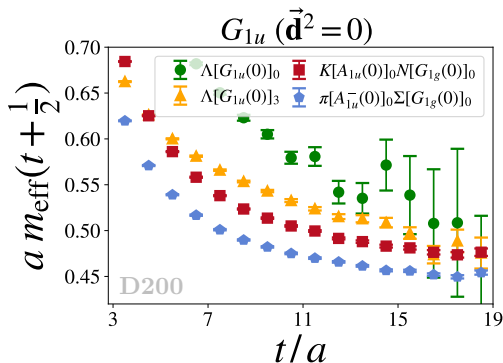
$$C(t) = \langle \mathcal{O}_2(t_f) \bar{\mathcal{O}}_1(t_i) \rangle = \sum_n A_n e^{-tE_n}$$

### ► Extraction of energy spectra → Solving the Generalized Eigenvalue Problem (GEVP)

[NPB 215 (1983) 433], [JHEP 04 (2009) 094]

$$C(t_d) \vec{v}_n(t_o, t_d) = \lambda_n(t_o, t_d) C(t_o) \vec{v}_n(t_o, t_d)$$

The  $\Lambda(1405)$  and the  $\Xi(1620)/\Xi(1690)$  lie **near meson-baryon thresholds**: requiring **multi-hadron operators** to properly resolve the energy spectrum.



Variety of fit forms employed in this work to extract the finite-volume energy spectra based on:

$$C(t) = \sum_n A_n e^{-tE_n}$$

$$C(t) = Ae^{-tE_n}$$

Single-exponential

$$C(t) = Ae^{-tE_n} [1 + Be^{-t\Delta E_n}]$$

Double-exponential

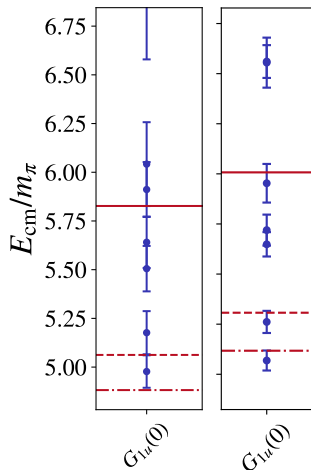
$$C(t) = \frac{Ae^{-tE_n}}{1 - Be^{-Mt}}$$

Geometric

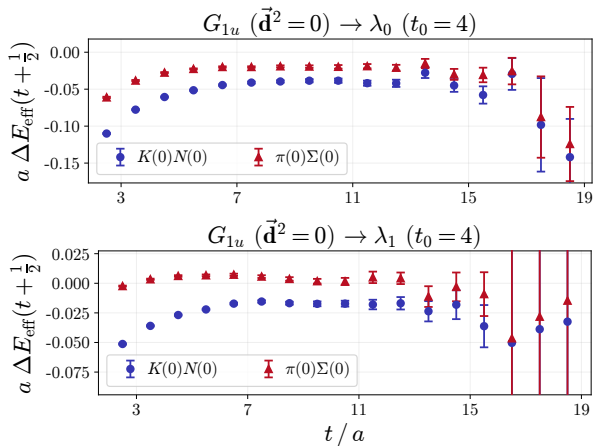
$$R_n(t) = \frac{D_n(t)}{C_A(\mathbf{d}_A^2, t)C_B(\mathbf{d}_B^2, t)} = A_n e^{-t\Delta E_n}$$

Ratio of correlators

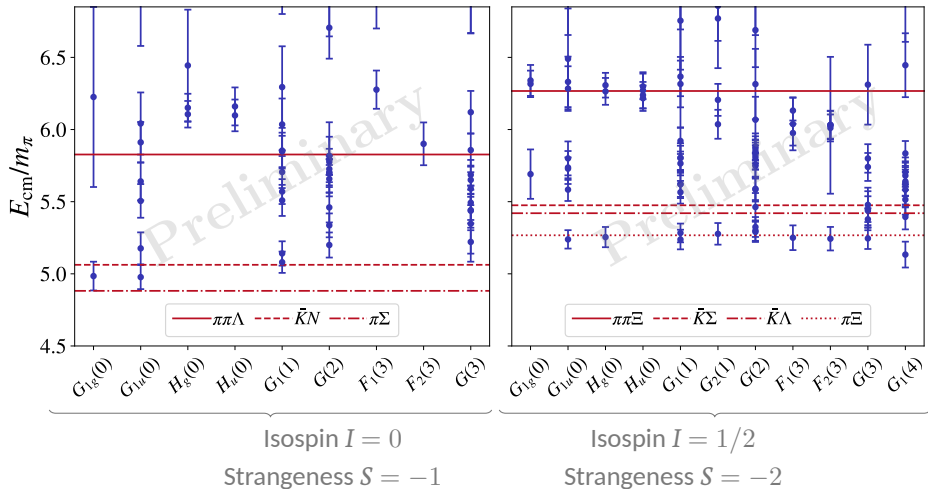
Single exponential



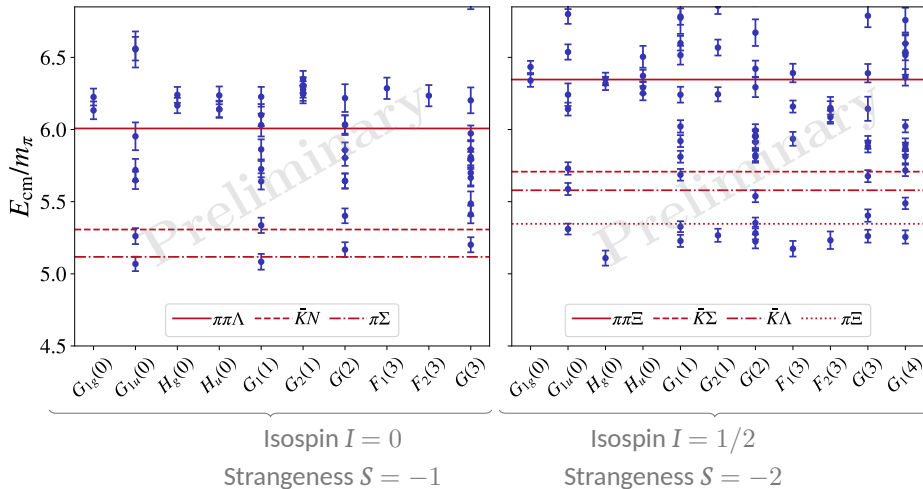
Ratio of correlators



$\sim 10^2$  measurements

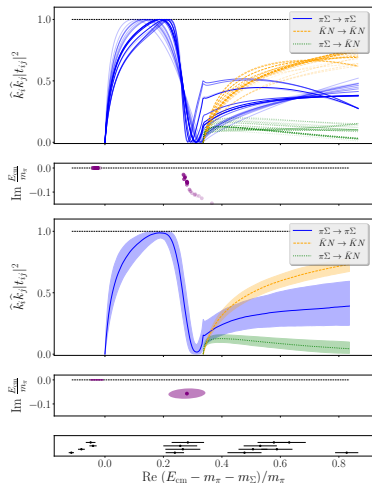


$\sim 10^3$  measurements



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Two poles were consistently found:

$$E_1 = 1392(9)_{\text{st}}(2)_{\text{md}}(16)_a \text{ MeV}$$

$$E_2 = 1455(13)_{\text{st}}(2)_{\text{md}}(17)_a - i11.5(4.4)_{\text{st}}(4)_{\text{md}}(0.1)_a \text{ MeV}$$

$$\left| \frac{c_{\pi\Sigma}^{(1)}}{c_{KN}^{(1)}} \right| = 1.9(4)_{\text{st}}(6)_{\text{md}} \quad \left| \frac{c_{\pi\Sigma}^{(2)}}{c_{KN}^{(2)}} \right| = 0.53(9)_{\text{st}}(10)_{\text{md}}$$

Lower pole  $\mapsto$  **Virtual bound state**

Upper pole  $\mapsto$  **Resonance**

[PRD **109** (2024) 5], [PRL **132** (2024) 1]

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- ✧ Lattice study included single- and multi-hadron operators, in order to explore the coupled-channel scattering amplitudes in the  $\Lambda(1405)$  and  $\Xi(1620)/\Xi(1690)$  region
- ✧ Lüscher formalism (D200):
  - Two-pole structure of the  $\Lambda(1405)$ : virtual bound state & resonance
  - Results in agreement with phenomenological extractions
- ✧ **Ongoing work:**
  - Full coupled-channel analysis on the X451 ( $\Lambda$  &  $\Xi$  sectors)
  - Exploration quark masses dependence of the poles
- ✧ Future plans:
  - Full coupled-channel analysis on the N451 ensemble
  - Inclusion of other meson-baryon systems with strangeness, for instance:  $\Sigma(1385)$ .
  - Impact of three-particle operators

Thanks