Baryons with strangeness and/or charm

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Understanding the Exotic Hadrons

- Suppose we try to describe all possible hadrons within the traditional quark model.

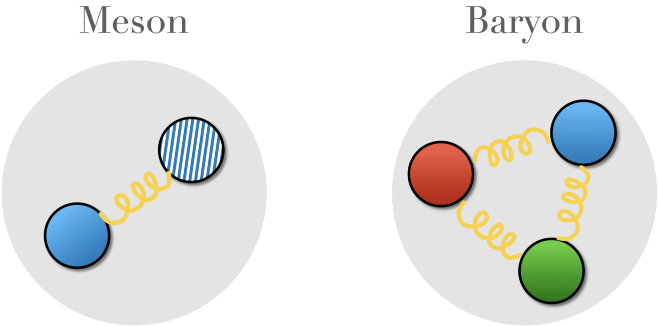


Figure: Available on StatNano[1]

[1] https://statnano.com/world-news/90354/Quantum-computers-take-on-quarks-—Physics-World

Understanding the Exotic Hadrons

- We face difficulties, especially in describing some excited states.
  - For example: $\Lambda(1405)$, $\phi(2170)$
- More complex configurations are needed to explain experimental data.
  - Compact multiquark states (tetraquarks, pentaquarks,...)
  - Glueballs
  - Hadronic molecules

QCD does not forbid such configurations. It only requires **color singlet** states!

Hadrons that cannot be described in terms of the traditional quark model are called **exotic hadrons**.

- Different internal structure and/or quantum numbers.

Exotic Configurations

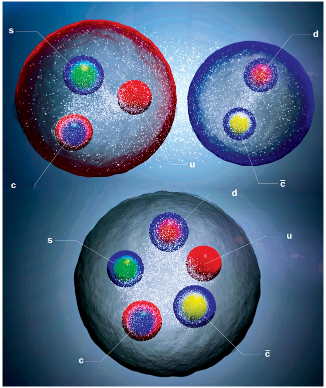


Figure: Available on CERN Courier[2]

[2]https://cerncourier.com/a/inside-pentaquarks-and-tetraquarks

How to study such systems theoretically?

- Low-energy region, i.e., non-perturbative QCD.
- Lattice QCD
- QCD sum rules
- Effective Lagrangians based on relevant symmetries.

E. Oset and A. Ramos. Nucl. Phys. A, 635:99–120, 1998. J. A. Oller and E. Oset. Nucl. Phys. A, 620:438–456, 1997. J. A. Oller, E. Oset, and J. R. Pelaez. Phys. Rev. D, 59:074001, 1999. L. Roca, C. Hanhart, E. Oset, and Ulf-G. Meissner. Eur. Phys. J. A, 27:373–380, 2006. L. S. Geng, F. K. Guo, C. Hanhart, R. Molina, E. Oset, and B. S. Zou. Eur. Phys. J. A, 44:305–311, 2010. H. Nagahiro, L. Roca, A. Hosaka, and E. Oset. Phys. Rev. D, 79:014015, 2009. A. Martínez Torres, D. Jido, Y. K. En'yo, Phys. Rev. C 83, 065205, 2011. A. Martinez Torres, K.P. Khemchandani, L.S. Geng, M. Napsuciale, E. Oset, Phys. Rev. D 78, 074031, 0801.3635., 2008. B. B. Malabarba, K.P. Khemchandani, A. Martínez Torres, Phys.Rev.D 108, 3, 036010, 2023. A. Martinez Torres, B. B. Malabarba, K.P. Khemchandani, EPJ Web Conf. 301, 03002, 2024.

How to study such systems theoretically?

- Low-energy region, i.e., non-perturbative QCD.
- Effective Lagrangians based on relevant symmetries.
- 2-body $\rightarrow \underbrace{a_0(980), f_0(980), \sigma(600)}_{K\bar{K},\pi\pi,\pi\eta}, \underbrace{\Lambda(1405)}_{\bar{K}N,\pi\Sigma,\pi\Lambda,K\Xi}, \underbrace{D^*_{s0}(2317)}_{DK}, \underbrace{D_{s1}(2460)}_{D^*K}, \underbrace{X(3872)}_{D\bar{D}^*/\bar{D}^*D}$.
- 3-body $\rightarrow \underbrace{\phi(2170)}_{\phi K\bar{K}}, \underbrace{K(1460)}_{KK\bar{K}}, \underbrace{N^*(1710)}_{N\pi\pi}$.
- But how can we infer about the exotic nature of these states? (multiquark, H-H, 3-H)

E. Oset and A. Ramos. Nucl. Phys. A, 635:99–120, 1998. J. A. Oller and E. Oset. Nucl. Phys. A, 620:438–456, 1997. J. A. Oller, E. Oset, and J. R. Pelaez. Phys. Rev. D, 59:074001, 1999. L. Roca, C. Hanhart, E. Oset, and Ulf-G. Meissner. Eur. Phys. J. A, 27:373–380, 2006. L. S. Geng, F. K. Guo, C. Hanhart, R. Molina, E. Oset, and B. S. Zou. Eur. Phys. J. A, 44:305–311, 2010. H. Nagahiro, L. Roca, A. Hosaka, and E. Oset. Phys. Rev. D, 79:014015, 2009. A. Martínez Torres, D. Jido, Y. K. En'yo, Phys. Rev. C 83, 065205, 2011. A. Martinez Torres, K.P. Khemchandani, L.S. Geng, M. Napsuciale, E. Oset, Phys. Rev. D 78, 074031, 0801.3635., 2008. B. B. Malabarba, K.P. Khemchandani, A. Martínez Torres, Phys.Rev.D 108, 3, 036010, 2023. A. Martinez Torres, B. B. Malabarba, K.P. Khemchandani, EPJ Web Conf. 301, 03002, 2024.

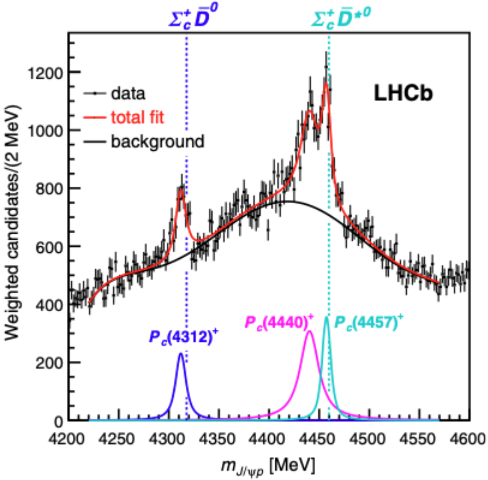
Different Observables

- Cross sections
- Scattering lengths and effective ranges
- Decay widths
- Invariant mass distributions
- Correlation functions

$\Rightarrow$ Compare with experimental data!

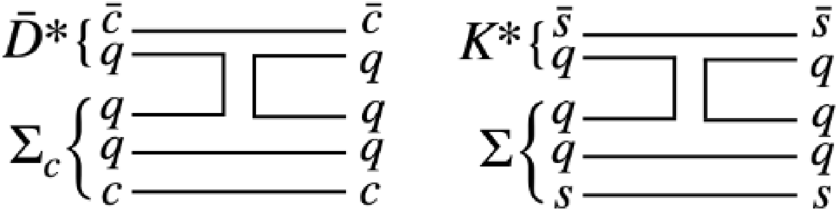
N^* resonance with hidden strangeness

The P_c states



- The $P_c(4457)$ ($J^P = 3/2^-$, $I = 1/2$) is 8 MeV below the $D^*\Sigma_c$ threshold.

The hidden strangeness analogy



- The same underlying dynamics $\Rightarrow$ 8 MeV below the $K^*\Sigma$ threshold.
- Mass $\sim$ 2077 MeV.
- Theoretical works have predicted the existence of a hidden strangeness nucleon.
- No direct observation has been made (only PWA) due to many N^* resonances in this energy

Jun He. Phys. Rev. D, 95(7):074031, 2017
Yong-Hui Lin, Chao-Wei Shen, and Bing-Song Zou. Nucl. Phys. A, 980:21–31, 2018
K. P. Khemchandani, H. Kaneko, H. Nagahiro, and A. Hosaka. Phys. Rev. D, 83:114041, 2011.

$N(1875)\ 3/2^-$

$I(J^P) = \frac{1}{2}(\frac{3}{2}^-)$ Status: ∗∗∗

was $N(2080)$

Before the 2012 *Review*, all the evidence for a $J^P = 3/2^-$ state with a mass above 1800 MeV was filed under a two-star $N(2080)$. There is now evidence from ANISOVICH 12A for two $3/2^-$ states in this region, so we have split the older data (according to mass) between a three-star $N(1875)$ and a two-star $N(2120)$.

N(1875) POLE POSITION

REAL PART

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
1850 to 1950 (≈ 1900) OUR ESTIMATE				
1870 ± 20	SOKHOYAN	15A	DPWA	Multichannel
1880 ± 100	CUTKOSKY	80	IPWA	$\pi N \to \pi N$ (lower m)
• • • We do not use the following data for averages, fits, limits, etc. • • •				
1993	HUNT	19	DPWA	Multichannel
1810	SHKLYAR	13	DPWA	Multichannel
1860 ± 25	ANISOVICH	12A	DPWA	Multichannel
1957 ± 49	BATINIC	10	DPWA	$\pi N \to N\pi$, $N\eta$
1824	VRANA	00	DPWA	Multichannel

$N(2120)\ 3/2^-$

$I(J^P) = \frac{1}{2}(\frac{3}{2}^-)$ Status: ∗∗∗

Before the 2012 *Review*, all the evidence for a $J^P = 3/2^-$ state with a mass above 1800 MeV was filed under a two-star $N(2080)$. There is now evidence from ANISOVICH 12A for two $3/2^-$ states in this region, so we have split the older data (according to mass) between a three-star $N(1875)$ and a two-star $N(2120)$.

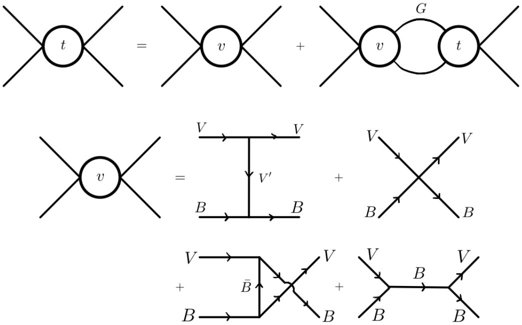
$N(2120)$ POLE POSITION

REAL PART

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
2050 to 2150 (≈ 2100) OUR ESTIMATE				
2115±40	SOKHOYAN	15A	DPWA	Multichannel
2094± 7±11	SVARC	14	L+P	$\pi N \to \pi N$
2050±70	CUTKOSKY	80	IPWA	$\pi N \to \pi N$ (higher m)
• • • We do not use the following data for averages, fits, limits, etc. • • •				
2357	HUNT	19	DPWA	Multichannel
2115±40	GUTZ	14	DPWA	Multichannel
2110±50	ANISOVICH	12A	DPWA	Multichannel

The $P_s(2080)$

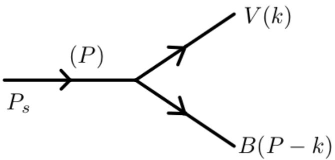
- By considering coupled channel $K^*\Sigma$, $K^*\Lambda$, ϕN, ωN and ρN vector-baryon dynamics a $J^P = 3/2^-$ N^* resonance was found with mass of $\simeq 2071$ MeV and a width of $\simeq 60 - 70$ MeV.

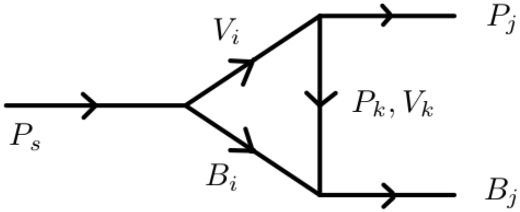


- In analogy with P_c states, we use the name $P_s(2080)$.

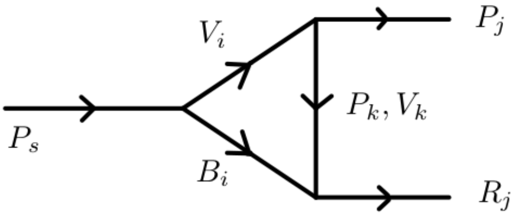
K. P. Khemchandani, H. Kaneko, H. Nagahiro, and A. Hosaka. Phys. Rev. D, 83:114041, 2011.
K. P. Khemchandani, A. Martinez Torres, H. Nagahiro, and A. Hosaka. Phys. Rev.D, 88(11):114016, 2013.

Decay Mechanisms





$P_s(2080)$ decaying, via triangular loop, into PB channels like πN, ηN, $K\Sigma$.

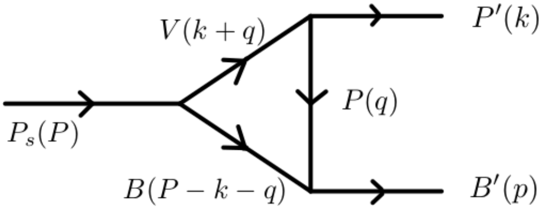


$P_s(2080)$ decaying, via triangular loop, into PR channels. Resonances are $\Lambda(1405)$, $N^*(1535)$ and $N^*(1650)$.

$P_s \to P'B'$

- Considering, for instance, the process $P_s \to P'B'$, exchanging a pseudoscalar, we can write the amplitude

$$-it^{VBP}_{P_s \to P'B'} = \int \frac{d^4q}{(2\pi)^4}(-it_{PB\to B'})iG_B(-it_{P_s\to VB})iG_V(-it_{V\to PP'})iG_P, \qquad (1)$$



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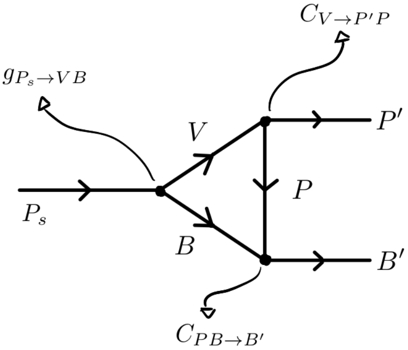
$$= -gC_{PB\to B'}C_{V\to PP'}g_{P_s\to VB}\int \frac{d^4q}{(2\pi)^4}\overbrace{\left[\bar{u}_{B'}(p)\gamma^\mu\gamma_5 u_B(P-k-q)q_\mu\right]}^{PB\to B'}$$
$$\times \underbrace{\left[\bar{u}_B(P-k-q)\epsilon^\nu(k+q)u_{P_{s\nu}}(P)\right]}_{P_s\to VB}\underbrace{\left[\epsilon^\alpha(k+q)(q_\alpha-k_\alpha)\right]}_{V\to PP'}$$
$$\times \frac{2m_B}{(P-k-q)^2-m_B^2+i\epsilon}\frac{1}{(k+q)^2-m_V^2+i\epsilon}\frac{1}{q^2-m_P^2+i\epsilon}. \qquad (2)$$

Pseudoscalar exchange

- In terms of the $a_j^{(i)}$ coefficients, the amplitude for the process $P_s \to P'B'$, considering the different VPB intermediate states

$$-it^{\text{pseudo}}_{P_s\to P'B'} = -i\sum_{VPB} t^{VPB}_{P_s\to P'B'}, \quad (3)$$

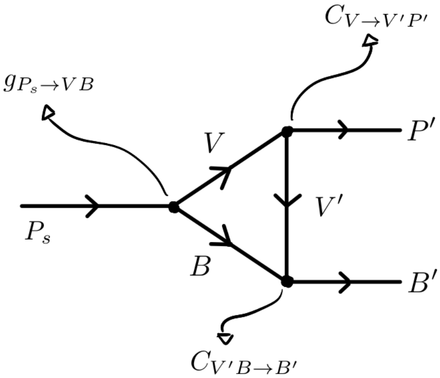


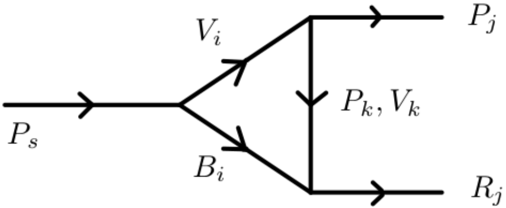
Some coefficients...

VBP	$C_{V\to PP'}$ $\pi^0 p/\pi^0 N^{*+}$	$C_{BP\to B'}$ $\pi^0 p$
$K^{*0}\Sigma^+K^0$	$1/\sqrt{2}$	$(-D+F)/(\sqrt{2}f_\pi)$
$K^{*+}\Sigma^0K^+$	$-1/\sqrt{2}$	$(-D+F)/(2f_\pi)$
$K^{*+}\Lambda K^+$	$-1/\sqrt{2}$	$(D+3F)/(2\sqrt{3}f_\pi)$
$\rho^0 p\pi^0$	0	$-(D+F)/(2f_\pi)$
$\rho^0 p\eta$	0	$(C_\beta(D-3F)+2\sqrt{2}DS_\beta)/(2\sqrt{3}f_\pi)$
$\rho^0 p\eta'$	0	$(-2\sqrt{2}DC_\beta+(D-3F)S_\beta)/(2\sqrt{3}f_\pi)$
$\rho^+ n\pi^+$	$-\sqrt{2}$	$-(D+F)/(\sqrt{2}f_\pi)$
$\omega p\pi^0$	0	$-(D+F)/(2f_\pi)$
$\omega p\eta$	0	$(C_\beta(D-3F)+2\sqrt{2}DS_\beta)/(2\sqrt{3}f_\pi)$
$\omega p\eta'$	0	$(-2\sqrt{2}DC_\beta+(D-3F)S_\beta)/(2\sqrt{3}f_\pi)$
$\phi p\pi^0$	0	$-(D+F)/(2f_\pi)$
$\phi p\eta$	0	$(C_\beta(D-3F)+2\sqrt{2}DS_\beta)/(2\sqrt{3}f_\pi)$
$\phi p\eta'$	0	$(-2\sqrt{2}DC_\beta+(D-3F)S_\beta)/(2\sqrt{3}f_\pi)$

VBP	$C_{V\to PP'}$	$C_{BP\to B'}$
$K^{*0}\Sigma^+\pi^0$	$-1/\sqrt{2}$	$-F/f_\pi$
$K^{*0}\Sigma^+\eta$	$\sqrt{3/2}C_\beta$	$(-DC_\beta+\sqrt{2}DS_\beta)/(\sqrt{3}f_\pi)$
$K^{*0}\Sigma^+\eta'$	$\sqrt{3/2}S_\beta$	$-D(\sqrt{2}C_\beta+S_\beta)/(\sqrt{3}f_\pi)$
$K^{*0}\Sigma^0\pi^+$	1	F/f_π
$K^{*0}\Lambda\pi^+$	1	$-D/(\sqrt{3}f_\pi)$
$\rho^0 p\bar{K}^0$	$1/\sqrt{2}$	$(-D+F)/(\sqrt{2}f_\pi)$
$\omega p\bar{K}^0$	$-1/\sqrt{2}$	$(-D+F)/(\sqrt{2}f_\pi)$
$\phi p\bar{K}^0$	1	$(-D+F)/(\sqrt{2}f_\pi)$

Other Contributions





Partial decay widths

- The partial decay widths of $P_s(2080)$ to $PB'(R)$ channels can be determined from

$$\Gamma_{P_s\to PB'(R)}(m_{P_s}, m_P, m_{B'(R)}) = \frac{m_{B'(R)}}{m_{P_s}}\frac{|\boldsymbol{p}_i|}{2\pi}\frac{1}{2S_{P_s}+1} \times \sum_{\text{pol.}} |t_{P_s\to PB'(R)}|^2 \Theta(m_{P_s} - m_P - m_{B'(R)}). \quad (4)$$

For instance,

$$\sum_{\text{pol.}} |t^{\text{pseudo}}_{P_s\to P'B'}|^2 = \frac{|g|^2}{4m_{B'}m_{P_s}} \sum_{\ell=0}^{5} F^{(\ell)}(P\cdot k)^{\ell}, \quad (5)$$

where

$$F^{(\ell)} = F^{(\ell)}_{11}|A_1|^2 + 2F^{(\ell)}_{13}\text{Re}\{A_1A_3^*\} + 2F^{(\ell)}_{14}\text{Re}\{A_1A_4^*\} + \ldots,$$
$$F^{(0)}_{11} = \frac{32}{3}m_{P_s}(m_{P_s} - m_{B'})m^2_{P'}, \; F^{(0)}_{13} = \frac{16}{3}(m_{B'} - 2m_{P_s})m_{P_s}m^4_{P'}, \; \ldots$$

Results

channel	width		channel	width	
	P exch.	P+V exch.		P exch.	P+V exch.
$\pi^+ n$	0.77 ± 0.21	0.95 ± 0.27	$K^+\Lambda_2(1405)$	5.05 ± 0.76	5.10 ± 0.77
$\pi^0 p$	0.38 ± 0.11	0.47 ± 0.13	$\pi^+ N^{*0}(1535)$	1.18 ± 0.28	1.18 ± 0.28
ηp	0.87 ± 0.23	0.77 ± 0.21	$\pi^0 N^{*+}(1535)$	0.59 ± 0.14	0.59 ± 0.14
$K^+\Lambda$	3.83 ± 0.84	3.74 ± 0.82	$\eta N^{*0}(1535)$	0.33 ± 0.05	0.34 ± 0.06
$K^+\Sigma^0$	1.56 ± 0.31	1.45 ± 0.29	$\pi^+ N^{*0}(1650)$	0.34 ± 0.03	0.26 ± 0.02
$K^0\Sigma^+$	3.11 ± 0.62	2.90 ± 0.57	$\pi^0 N^{*+}(1650)$	0.17 ± 0.01	0.13 ± 0.01
$\eta' p$	0.014 ± 0.005	0.07 ± 0.02			
$K^+\Lambda_1(1405)$	16.97 ± 2.67	17.16 ± 2.71			

Results

- The $K^*\Sigma$ gives the biggest contribution, but its threshold is above the P_s mass (~ 2085 MeV). If the convolution were not included, we would neglect this contribution.

channel	width
ρN	5.66
ωN	1.33
ϕN	1.92
$K^*\Lambda$	6.64
$K^*\Sigma$	49.97

- Final states one could search for the $P_s(2080)$:
  - $K^+\Lambda_1(1405) \to K(\pi\Sigma)$.
  - $\pi N^*(1535) \to \pi\pi N$
  - $K^*\Sigma \to (\pi K)\Sigma$.

Extracting correlation functions and scattering parameters from the $n\bar{D}_{s1}(2460)$ system

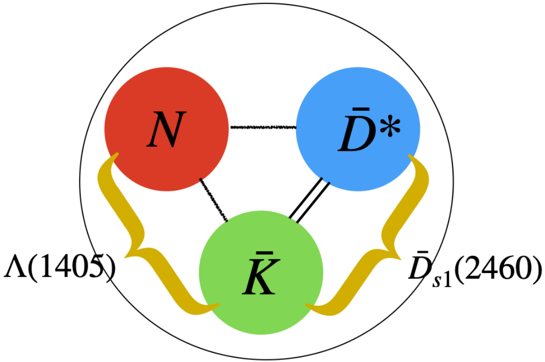
Probing Hadron Interactions via Correlation Functions

- Femtoscopic correlation functions are now a powerful tool in high-energy nuclear and particle physics.
- The correlation function $C(p) = \frac{A(p)}{B(p)}$ measures deviations of the observed pair distribution from an uncorrelated baseline, reflecting the influence of final-state interactions at low relative momentum.
- Experimental collaborations such as ALICE, STAR, and Belle II have already measured hadronic correlation functions, including $p\Lambda$, pK, and $p\Xi$.
- Recently, measurements of the K^+d and pd correlation functions have demonstrated the potential for extending such studies to the charm sector.
- The $pf_1(1285)$ correlation function is being measured, which could be understood as a 3-body molecule.

ALICE Collaboration, Phys. Lett. B 802, 135225 (2020). STAR Collaboration, Nature 614, 244 (2023).
Belle Collaboration, Phys. Rev. D 105, 112011 (2022). ALICE Collaboration, Phys. Rev. X 14, 031051 (2024).
L. Šerkšnytė, S. Kundu, M. Korwieser, Private communication P. Encarnación, A. Feijoo, E. Oset, Phys. Rev. D 111, 114023 (2025).

Why the $n\bar{D}_{s1}$ Systems?

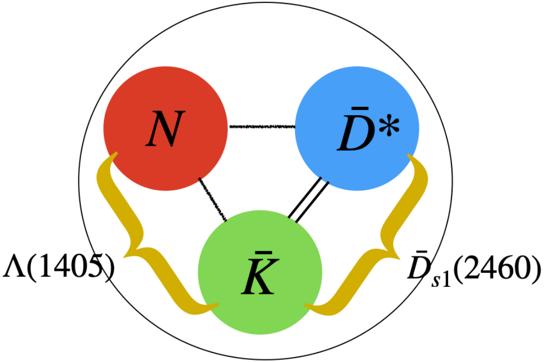
- The $D_{s1}(2460)$ and $D_{s1}(2536)$ can be dynamically generated from KD^* and K^*D interactions in coupled-channel unitarized models. Lattice QCD results also support these hypotheses.



D. Gamermann, E. Oset, D. Strottman, M. J. Vicente Vacas, Phys. Rev. D 76, 074016 (2007). D. Mohler, C.B. Lang, L. Leskovec, S. Prelovsek, R.M. Woloshyn, Phys.Rev.Lett. 111, 22, 222001 (2013). P. G. Ortega, J. Segovia, D. R. Entem, F. Fernández, Phys. Rev. D 94, 074037 (2016) A. Martínez Torres, E. Oset, S. Prelovsek, A. Ramos, JHEP 05, 153 (2015).

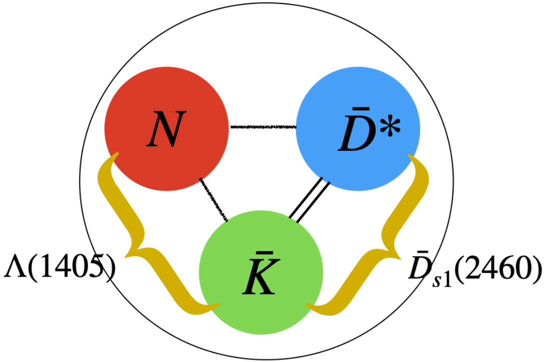
Why the $n\bar{D}_{s1}$ Systems?

- The neutron is chosen to avoid Coulomb effects, isolating the strong-interaction dynamics.



Why the $n\bar{D}_{s1}$ Systems?

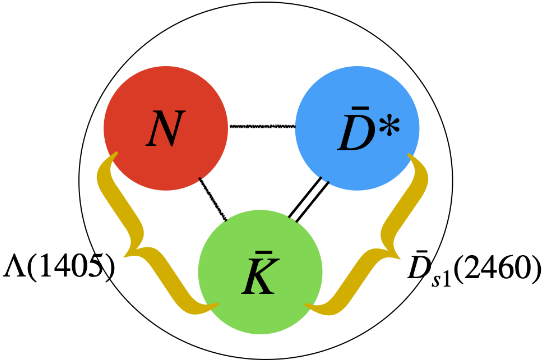
- The use of $\bar{D}_{s1}$ is motivated by the attractive $n\bar{K}$ interaction, which dynamically generates the $\Lambda(1405)$.



E. Oset, A. Ramos, Nucl. Phys. A 635, 99 (1998).

Why the $n\bar{D}_{s1}$ Systems?

- A similar study of the $n\bar{D}^*_{s0}(2317)$ system (done in parallel) has reported a state below the threshold; the present work extends this analysis to the axial D_{s1} sector.



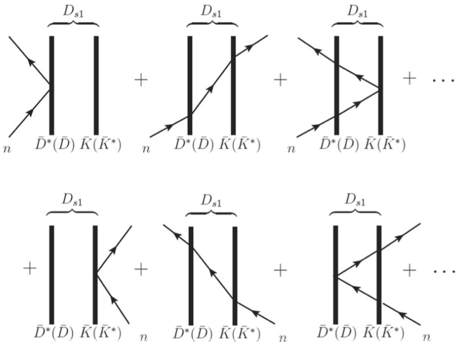
N. Ikeno, E. Oset, arXiv:2507.16367 [hep-ph] (2025).

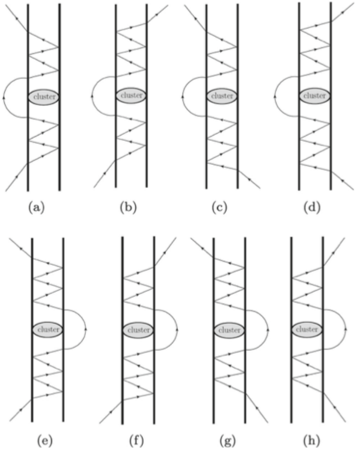
Objectives

- Solve the Faddeev equations using the Fixed Center Approximation (FCA) with exact unitarity.
- Compute T-matrices and then, observables as scattering lengths and effective ranges.
- Search for subthreshold states.
- Use correlation functions to extract scattering information on the $n\bar{D}_{s1}$ systems.

Faddeev Equations with Fixed Center Approximation (FCA)

- The FCA simplifies the three-body Faddeev equations by assuming one pair (the cluster) is bound and acts as a fixed center.

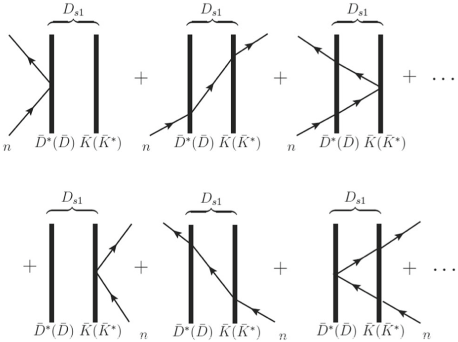


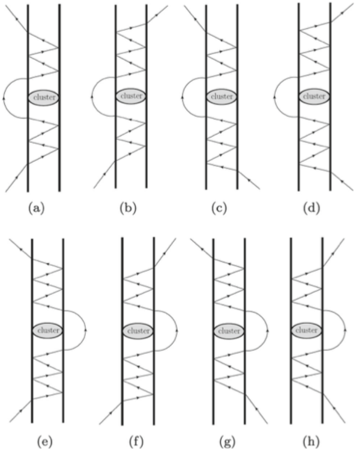


P. Encarnación, A. Feijoo, E. Oset, Phys. Rev. D 111, 114023 (2025).

Faddeev Equations with Fixed Center Approximation (FCA)

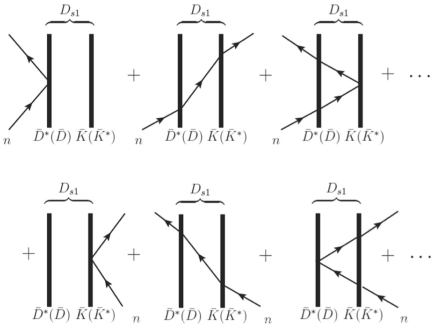
- The third particle (neutron) interacts with each component of the cluster through multiple scattering.





P. Encarnación, A. Feijoo, E. Oset, Phys. Rev. D 111, 114023 (2025).

Faddeev Equations with FCA



- The coupled equations for the partition functions $\tilde{T}_{ij}$ are

$$\tilde{T}_{11} = t_1 + t_1 G_0 \tilde{T}_{21}, \quad \tilde{T}_{12} = t_1 G_0 \tilde{T}_{22},$$
$$\tilde{T}_{21} = t_2 G_0 \tilde{T}_{11}, \quad \tilde{T}_{22} = t_2 + t_2 G_0 \tilde{T}_{12}. \tag{6}$$

Unitarized FCA

- The sum over all possible contributions needs to be iterated, leading to a Lippmann-Schwinger equation

$$\begin{aligned}\mathbb{T} &= \tilde{T} + \tilde{T} G_C \mathbb{T} \\ &= \left[1 - \tilde{T} G_C\right] \tilde{T}\end{aligned} \tag{7}$$

where $\tilde{T} = \begin{pmatrix} \tilde{T}_{11} & \tilde{T}_{12} \\ \tilde{T}_{21} & \tilde{T}_{22} \end{pmatrix}$ and $G_C = \begin{pmatrix} G_C^{(1)} & 0 \\ 0 & G_C^{(2)} \end{pmatrix}$.

- The total amplitude is

$$\begin{aligned}T &= \sum_{i,\ j\ =\ 1}^{2} \mathbb{T}_{ij} \\ &= \frac{\tilde{T}_{11} + 2\tilde{T}_{12} + \tilde{T}_{22} + (\tilde{T}_{12}^2 - \tilde{T}_{11}\tilde{T}_{22})\left(G_C^{(1)} + G_C^{(2)}\right)}{1 - \tilde{T}_{11} G_C^{(1)} - \tilde{T}_{22} G_C^{(2)} - (\tilde{T}_{12}^2 - \tilde{T}_{11}\tilde{T}_{22}) G_C^{(1)} G_C^{(2)}}.\end{aligned} \tag{8}$$

Unitarized FCA

- The total amplitude is

$$T = \sum_{i,\ j\ =\ 1}^{2} \mathbb{T}_{ij}$$
$$= \frac{\tilde{T}_{11} + 2\tilde{T}_{12} + \tilde{T}_{22} + (\tilde{T}_{12}^2 - \tilde{T}_{11}\tilde{T}_{22})\left(G_C^{(1)} + G_C^{(2)}\right)}{1 - \tilde{T}_{11}G_C^{(1)} - \tilde{T}_{22}G_C^{(2)} - (\tilde{T}_{12}^2 - \tilde{T}_{11}\tilde{T}_{22})G_C^{(1)}G_C^{(2)}}. \tag{7}$$

- In terms of the two-body amplitudes, we write

$$T = \frac{t_1 + t_2 + (2G_0 - G_C^{(1)} - G_C^{(2)})t_1 t_2}{1 - G_C^{(1)}t_1 - G_C^{(2)}t_2 - (G_0^2 - G_C^{(1)}G_C^{(2)})t_1 t_2}. \tag{8}$$

- It satisfies exactly the 2-body unitarity condition

$$\frac{8\pi\sqrt{s}}{2M_N}\,\mathrm{Im}\{T^{-1}\} = q_{cm}. \tag{9}$$

Correlation Function

- We write the correlation function accounting for the coherent propagation as

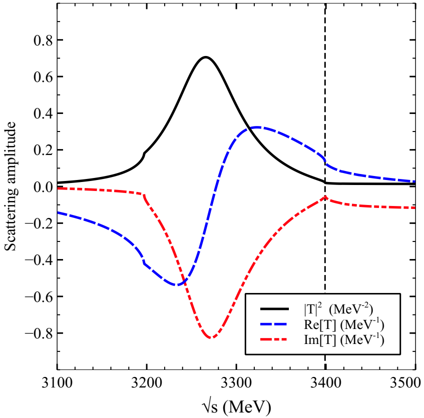
$$C_{n\bar{D}_{s1}}(p) = 1 + 4\pi \int_0^\infty dr\, r^2 S_{12}(r) \Big(|j_0(pr) + T'G'|^2 - j_0^2(pr) \Big), \tag{10}$$

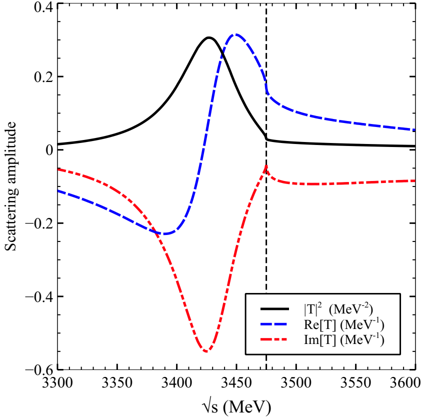
where $S_{12}(r) = \frac{e^{-r^2/4R^2}}{(4\pi R^2)^{3/2}}$, $T'G' = (\mathbb{T}_{11} + \mathbb{T}_{21})G_1(\sqrt{s}, r) + (\mathbb{T}_{12} + \mathbb{T}_{22})G_2(\sqrt{s}, r)$.
And the propagators $G_1(\sqrt{s}, r)$, $G_2(\sqrt{s}, r)$ are

$$\begin{aligned} G_1(\sqrt{s}, r) &= \int \frac{d^3q}{(2\pi)^3} \frac{M_N}{\omega_N(\vec{q})} \frac{1}{2\omega_C(\vec{q})} \frac{j_0(qr) F_C^{(1)}(\vec{q})}{\sqrt{s} - \omega_N(\vec{q}) - \omega_C(\vec{q}) + i\epsilon}, \\ G_2(\sqrt{s}, r) &= \int \frac{d^3q}{(2\pi)^3} \frac{M_N}{\omega_N(\vec{q})} \frac{1}{2\omega_C(\vec{q})} \frac{j_0(qr) F_C^{(2)}(\vec{q})}{\sqrt{s} - \omega_N(\vec{q}) - \omega_C(\vec{q}) + i\epsilon}. \end{aligned} \tag{11}$$

I. Vidana, A. Feijoo, M. Albaladejo, J. Nieves, E. Oset, Phys. Lett. B 846, 138201 (2023)

$n\bar{D}_{s1}$ Amplitudes

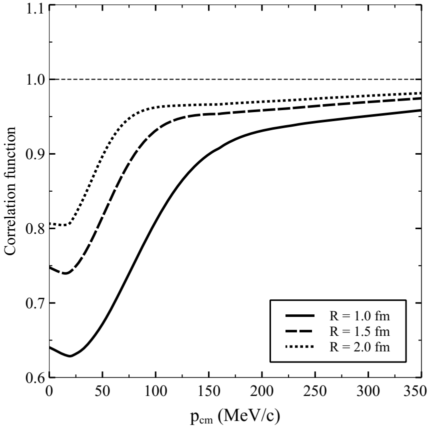


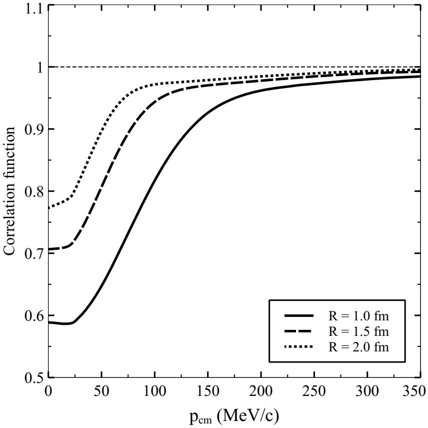


- Scattering parameters:

$$n\bar{D}_{s1}(2460) \to a = (0.59 - i0.21)\,\text{fm}, \quad r_0 = (0.65 - i0.16)\,\text{fm},$$
$$n\bar{D}_{s1}(2536) \to a = (0.71 - i0.18)\,\text{fm}, \quad r_0 = (0.16 + i0.32)\,\text{fm}.$$

Correlation functions





Conclusion

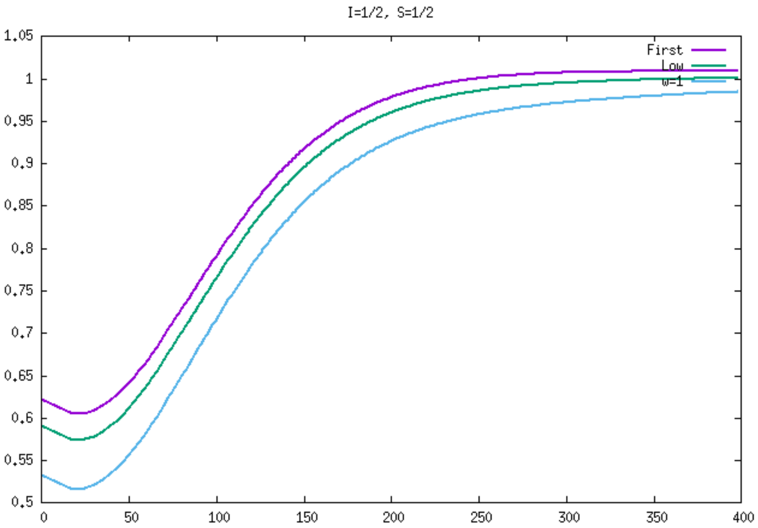
- Implemented an unitary FCA formalism for n–D_{s1} systems.
- Predicted resonances:
  - $n\bar{D}_{s1}(2460)$: $M \sim 3265$ MeV.
  - $n\bar{D}_{s1}(2536)$: $M \sim 3425$ MeV.
- The behavior of $C(p)$ follows the expected pattern for a state below threshold.

Calculating the $K^*\Sigma$ Correlation Function

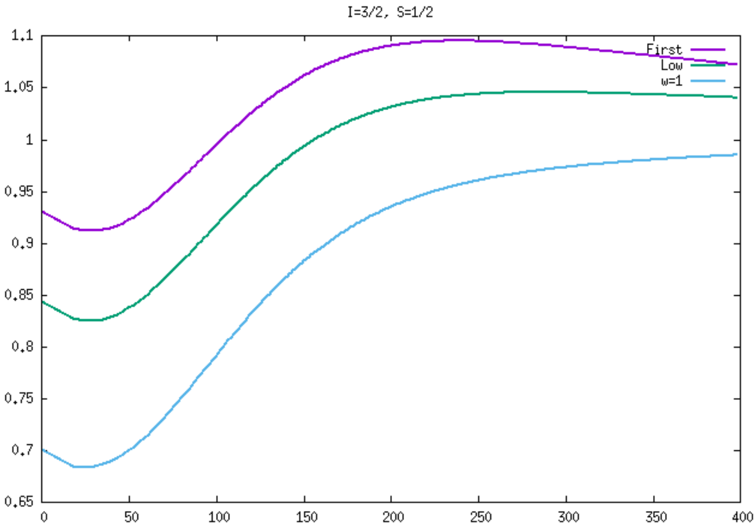
- Partial decay widths of P_s and large coupling to $K^*\Sigma$.
- Calculate the correlation function to search for a signal of P_s.
- By considering coupled-channels in different spin-isospin sectors, we can calculate the correlation function by using

$$C(p) = 1 + 4\pi \int_0^\infty dr\ r^2\ S_{12}(r) \Big[|j_0(kr) + T_{ii}\tilde{G}^{(i)}(r,\sqrt{s})|^2 + \sum_{j\neq i} \omega_j |T_{ji}\tilde{G}^{(j)}(r,\sqrt{s})|^2 - |j_0(kr)|^2 \Big] \quad (12)$$

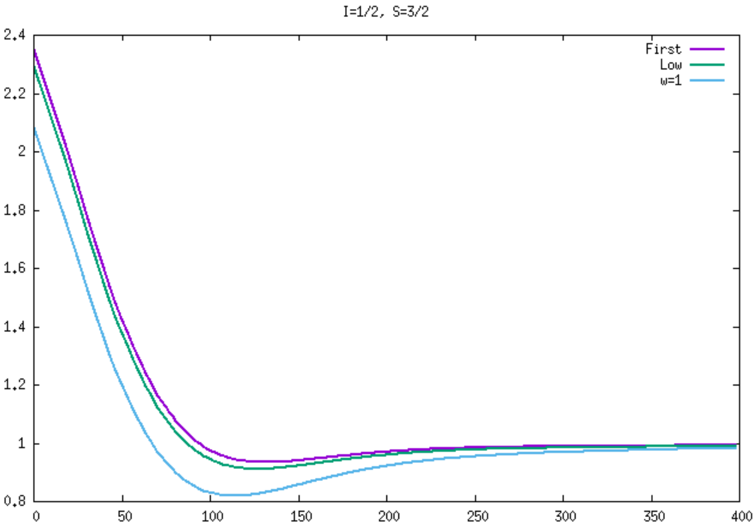
Preliminary Results



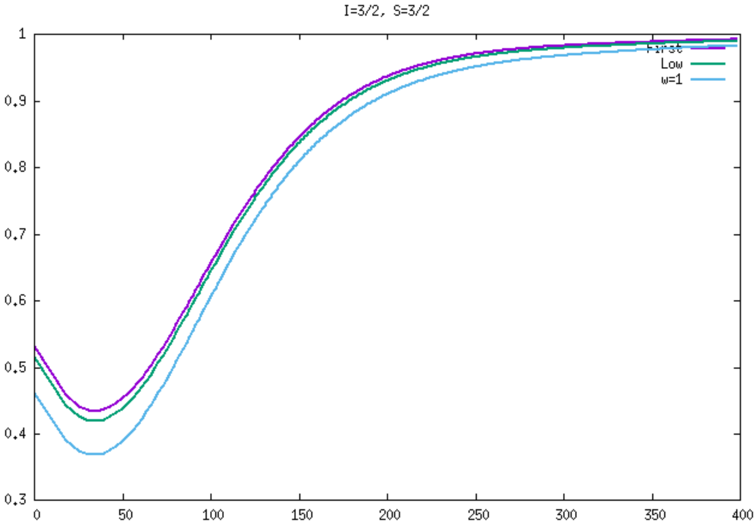
Preliminary Results



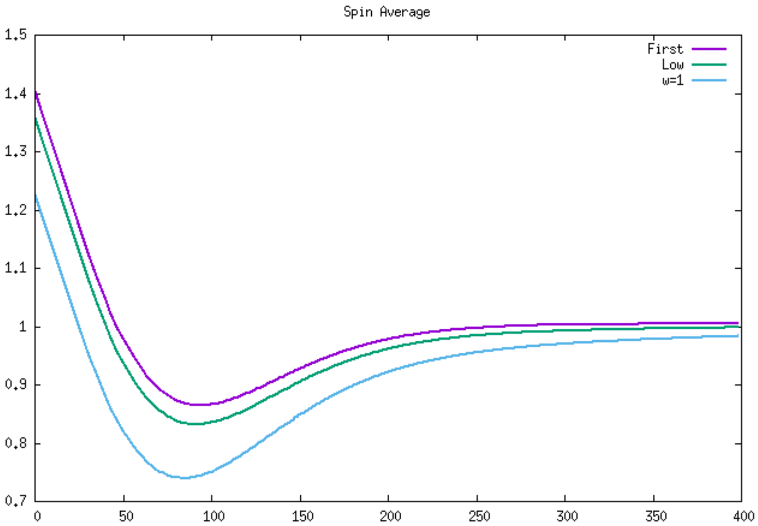
Preliminary Results



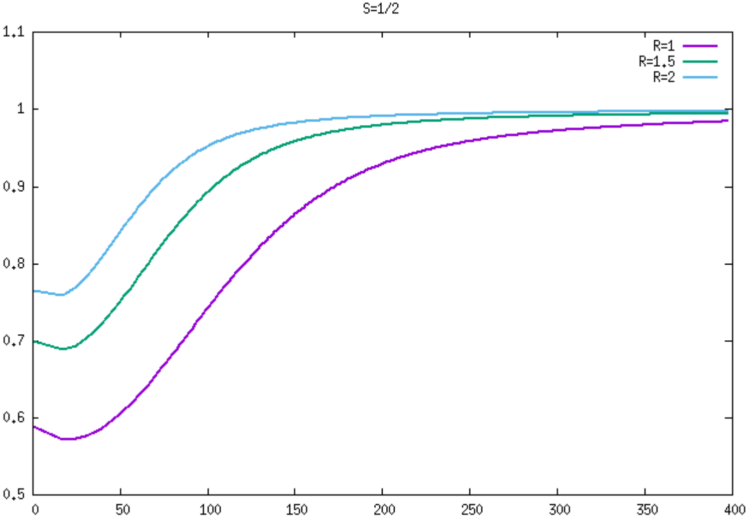
Preliminary Results



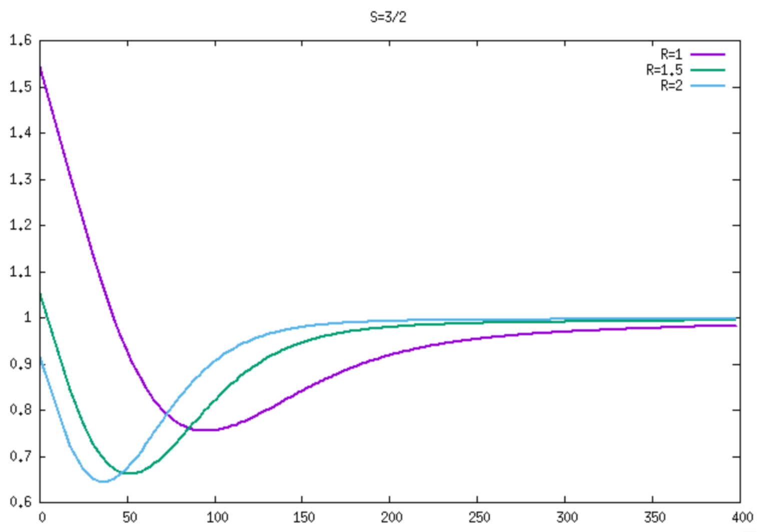
Preliminary Results



Preliminary Results



Preliminary Results



OBRIGADO!