Working Group 3

Reunião de 22/05/24

Alberto Martinez

Fernando Navarra

Renato Higa

Kanchan Khemchandani

WG3 : aprender física de hadrons no LHC (QCD, QGP, CGC, espectros...)

Sub-produto: melhorar o nível de discussão dentro do grupo e do IFUSP

Sub-grupo: produção de exóticos em colisões AA periféricas e no EIC
(Fernando Sobrinho, Celsina Azevedo, Luciano Abreu, Carlos Bertulani)

Sub-grupo: produção de exóticos em colisões AA centrais.
(Luciano Abreu, Alberto M. Torres)

Sub-grupo: busca da junção bariônica
(Fernando Navarra, Richard Terra)

Sub-grupo: distribuição de multiplicidades e CGC
(Fernando Navarra, Guilherme Germano, Henrique M. Fontes)

Sub-grupo: estrutura de exóticos
(Alberto M. Torres, Renato Higa, Kanchan Khemchandani, Breno Agatão)

O que aconteceu entre 05/24 e 10/24 ?

5 Artigos Publicados

inspirehep.net

(os que antes estavam submetidos)

Emergence of Koba-Nielsen-Olsen scaling in multiplicity distributions in jets produced at the LHC #1

G.R. Germano (Sao Paulo U.), F.S. Navarra (Sao Paulo U.), G. Wilk (NCBJ, Warsaw), Z. Wlodarczyk (Jan Kochanowski U.) (Jun 7, 2024)

Published in: *Phys.Rev.D* 110 (2024) 3, 034026 • e-Print: 2406.04856 [hep-ph]

pdf DOI cite claim reference search 0 citations

Production of meson molecules in ultraperipheral heavy ion collisons #2

F.C. Sobrinho (Sao Paulo U.), L.M. Abreu (Sao Paulo U. and Bahia U.), C.A. Bertulani (Texas A-M, Commerce and Darmstadt, Tech. Hochsch.), F.S. Navarra (Sao Paulo U.) (May 4, 2024)

Published in: *Phys.Rev.D* 110 (2024) 3, 034037 • e-Print: 2405.02645 [hep-ph]

pdf DOI cite claim reference search 2 citations

$X(3872)$ to $\psi(2S)$ yield ratio in heavy-ion collisions #3

L.M. Abreu (Bahia U. and Sao Paulo U.), F.S. Navarra (Sao Paulo U.), H.P.L. Vieira (Bahia U.) (Jan 20, 2024)

Published in: *Phys.Rev.D* 110 (2024) 1, 014011 • e-Print: 2401.11320 [hep-ph]

pdf DOI cite claim reference search 2 citations

Can a femtoscopic correlation function shed light on the nature of the lightest charm axial mesons? #4

K.P. Khemchandani (Sao Paulo State U.), Luciano M. Abreu (Sao Paulo U. and Bahia U.), A. Martinez Torres (Sao Paulo U.), F.S. Navarra (Sao Paulo U.) (Dec 18, 2023)

Published in: *Phys.Rev.D* 110 (2024) 3, 036008 • e-Print: 2312.11811 [hep-ph]

pdf DOI cite claim reference search 5 citations

Interaction of exotic states in a hadronic medium: the $Z_c(3900)$ case #5

L.M. Abreu (Bahia U. and Sao Paulo U.), R.O. Magalhães (Bahia U.), F.S. Navarra (Bahia U.), H.P.L. Vieira (Sao Paulo U.) (Oct 28, 2023)

Published in: *J.Phys.G* 51 (2024) 9, 095003 • e-Print: 2310.18747 [hep-ph]

pdf DOI cite claim reference search 2 citations

4 Artigos Submetidos

inspirehep.net

Hadronic scattering effects on $\psi(2S)$ suppression in relativistic heavy-ion collisions #1

L.M. Abreu (Bahia U. and Sao Paulo U.), F.S. Navarra (Sao Paulo U.), H.P.L. Vieira (Bahia U.) (Sep 19, 2024)

e-Print: 2409.12755 [hep-ph]

pdf cite claim reference search 0 citations

Nuclear Fragmentation at the Future Electron-Ion Collider #2

C.A. Bertulani, Y. Kucuk, F.S. Navarra (Aug 19, 2024)

e-Print: 2408.10157 [nucl-th]

pdf cite claim reference search 0 citations

Heavy K^* mesons with open charm from $KD^{(*)}D^*$ interactions #1

Xiu-Lei Ren, K.P. Khemchandani, A. Martínez Torres (Sep 24, 2024)

e-Print: 2409.16281 [hep-ph]

pdf cite claim reference search 0 citations

A study of the ϕN correlation function #2

Luciano M. Abreu (Bahia U.), Philipp Gubler (JAEA, Ibaraki and Sao Paulo U.), K.P. Khemchandani (Sao Paulo U.), A. Martinez Torres (Sao Paulo U.), Atsushi Hosaka (JAEA, Ibaraki and Sao Paulo U. and Osaka U., Res. Ctr. Nucl. Phys.) (Sep 8, 2024)

e-Print: 2409.05170 [hep-ph]

pdf cite claim reference search 0 citations

1 Publicação em Proceedings

How the hadron gas affects $X(3872)$ and $\psi(2S)$ production in heavy ion collisions

Luciano M. Abreu[1,*], *Fernando* S. Navarra[1,**], and *Hildeson* P.L. Vieira[1,***]

Proceedings of the QCD@Work- International Workshop on QCD – Theory and Experiment (2024); 18-21/6/24 Trani, Itália. EPJ Web of Conferences
(F. Navarra)

4 Participações em Conferências

Hadron spectroscopy and the new unexpected resonances, 22-28/9/24, Paraty, RJ
(F. Navarra, R. Higa, A. Martinez)

IV Encontro de Primavera da SBF, 24-27/9/24, Belo Horizonte, MG
(A. Martinez)

4 Teses Concluidas

Nathalia Fukase (mestrado - Kanchan Khemchandani)

Vinicius B. B. Ader (mestrado - Renato Higa)

Murilo S. de Godoy (mestrado - Renato Higa)

Fernando César Sobrinho (mestrado – Fernando Navarra)

Organização de Eventos Científicos

Advances in QCD at the LHC and the EIC, 9-15/11/2025, Paraty, RJ
(Fernando Navarra)

Qualitativamente

Sub-grupo: produção de exóticos em colisões AA UPC e no EIC :

Refinamento do cálculo da seção de choque de produção do estado ligado D+D-

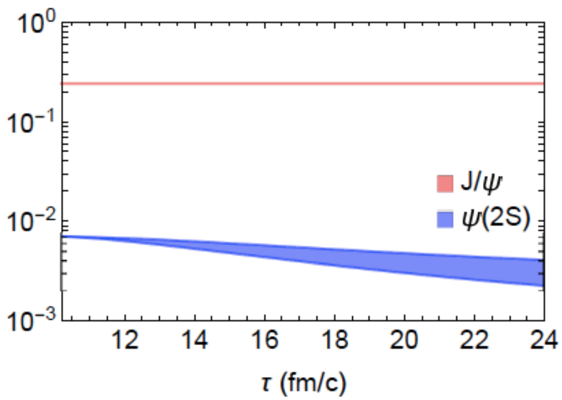
Extensão para o EIC (ver apresentação da Celsina Azevedo)

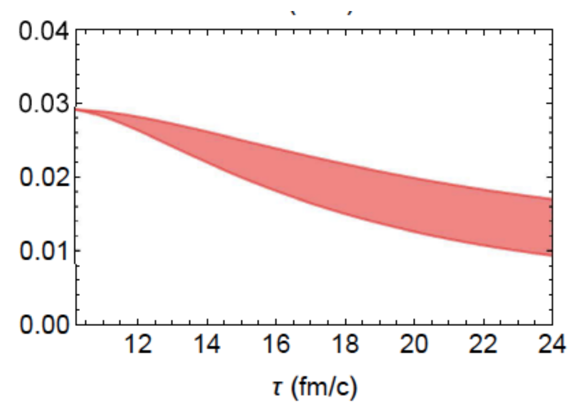
Estudo de fragmentação nuclear em UPC e no EIC

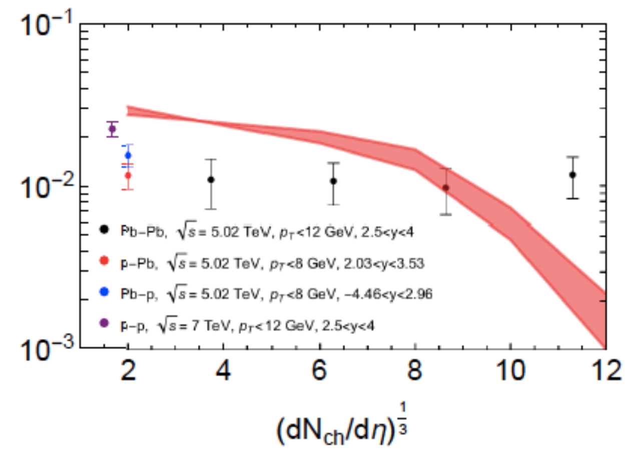
Nuclear Fragmentation at the Future Electron-Ion Collider
C.A. Bertulani, Y. Kucuk, F.S. Navarra (Aug 19, 2024)
e-Print: 2408.10157 [nucl-th]

Sub-grupo: produção de exóticos em colisões AA centrais

Extensão do cálculo X(3972)/Psi(2S) → Psi(2S)/J/psi







Femtoscopia

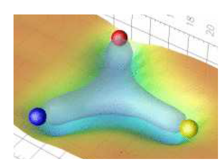
A study of the ϕN correlation function #2

Luciano M. Abreu (Bahia U.), Philipp Gubler (JAEA, Ibaraki and Sao Paulo U.), K.P. Khemchandani (Sao Paulo U.), A. Martinez Torres (Sao Paulo U.), Atsushi Hosaka (JAEA, Ibaraki and Sao Paulo U. and Osaka U., Res. Ctr. Nucl. Phys.) (Sep 8, 2024)

e-Print: 2409.05170 [hep-ph]

(ver apresentação do Alberto Martinez Torres)

Sub-grupo: busca da junção bariônica



Produção de charmonium em pp e pA (ver apresentação do Richard Terra)

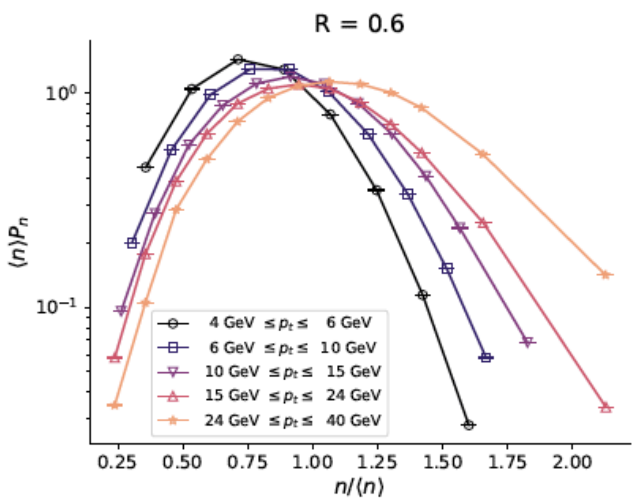
Sub-grupo: distribuição de multiplicidades e CGC

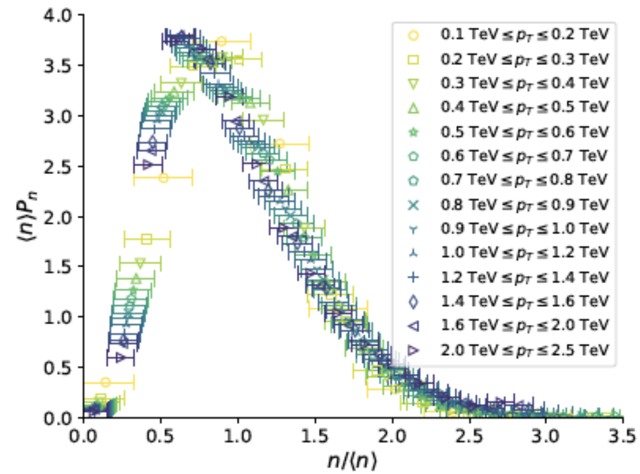
Scaling de KNO em jatos (Guilherme Germano)

Emergence of Koba-Nielsen-Olsen scaling in multiplicity distributions in jets produced at the LHC

G.R. Germano (Sao Paulo U.), F.S. Navarra (Sao Paulo U.), G. Wilk (NCBJ, Warsaw), Z. Wlodarczyk (Jan Kochanowski U.) (Jun 7, 2024)

Published in: *Phys.Rev.D* 110 (2024) 3, 034026 • e-Print: 2406.04856 [hep-ph]



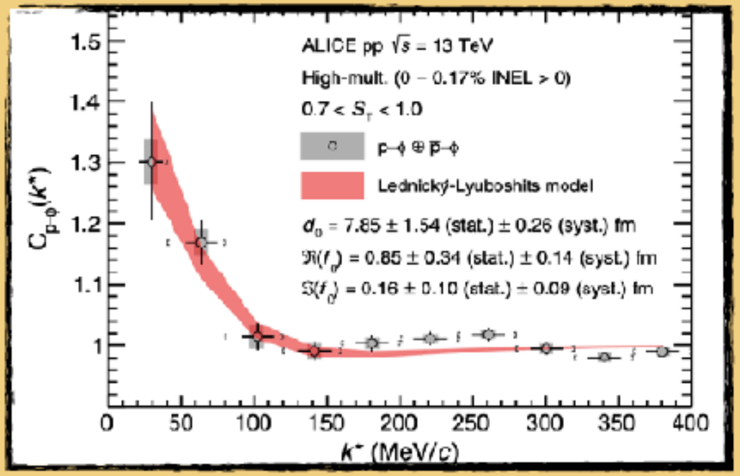


Separação da física soft e semi-hard nas distribuições de multiplicidade

(ver apresentação do Henrique M. Fontes)

ϕN CORRELATION FUNCTION

ALICE Collaboration, Phys. Rev. Lett 127, 172301 (2021)



- OZI rule: ϕN interaction biased (weak interaction: distinct quark content) $\Longrightarrow$ Studies of ϕ photo-production data suggest weak ϕN interaction.

- Lattice QCD [Hatsuda et al., PRD106,074507(2022)]: ϕN interaction in Spin 3/2 is attractive (they use $\phi - N$ currents, and neglect explicit coupled channels). Spin 1/2: too many coupled channels (complicated).

- Analysis of the ϕN correlation function without coupled channels and a phenomenological ϕN potential [Chizzali et al., PLB 848,138358 (2024)]: They use the spin 3/2 scattering length obtained by lattice in their $V_{3/2}$ potential and fit the spin 1/2 parameters in $V_{1/2} \Longrightarrow$ They find that spin 1/2 ϕN interaction is attractive (bound state with $\simeq$ 13-60 MeV of binding).

MODEL

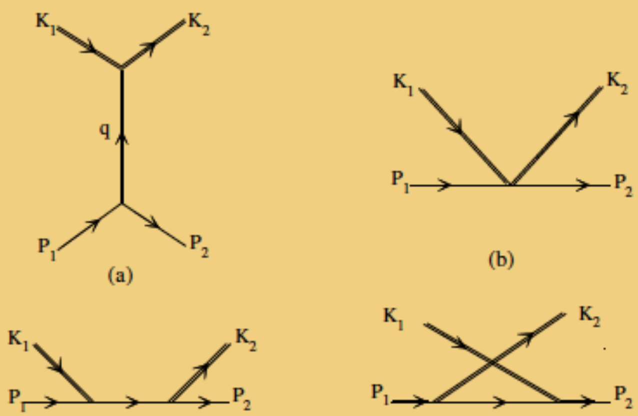
- Khemchandani et al., Phys. Rev. D83,114041 (2011)

$\rho N, \omega N, \phi N, K^*\Lambda, K^*\Sigma, \pi N, K\Sigma, K\Lambda, \eta N$

$N^*(1535)[J^P = 1/2^-], N^*(1650)[J^P = 1/2^-]$

$N^*(1700)[J^P = 3/2^-], N^*(2100)[J^P = 3/2^-]$

Hidden Local symmetry (Bando and collaborators)



$$\mathscr{L}_{VB} = -g\Big\{\langle \bar{B}\gamma_\mu \left[\mathbb{V}_8^\mu, B\right]\rangle + \langle \bar{B}\gamma_\mu B\rangle\langle \mathbb{V}_8^\mu\rangle + \frac{1}{4M}\Big(F\langle \bar{B}\sigma_{\mu\nu}\left[\mathbb{V}_8^{\mu\nu}, B\right]\rangle + D\langle \bar{B}\sigma_{\mu\nu}\left\{\mathbb{V}_8^{\mu\nu}, B\right\}\rangle\Big) + \langle \bar{B}\gamma_\mu B\rangle\langle \mathbb{V}_0^\mu\rangle + \frac{C_0}{4M}\langle \bar{B}\sigma_{\mu\nu}\mathbb{V}_0^{\mu\nu} B\rangle\Big\}$$

$$V_{\mathrm{VB}}^{I,S} = V_{t,\mathrm{VB}}^{I,S} + V_{s,\mathrm{VB}}^{I,S} + V_{u,\mathrm{VB}}^{I,S} + V_{\mathrm{CT,VB}}^{I,S}$$

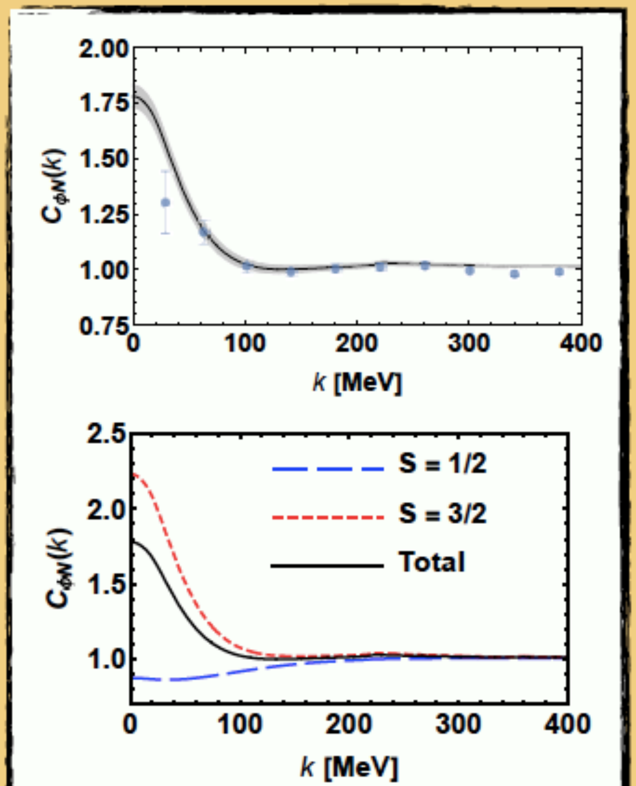
Spin-dependent interactions, Vector-Baryon and Pseudosclar-Baryon as coupled channels

K. P. Khemchandani, A. Martínez Torres, H. Nagahiro, A. Hosaka, Phys. Rev. D88, 114016 (2013).

RESULTS

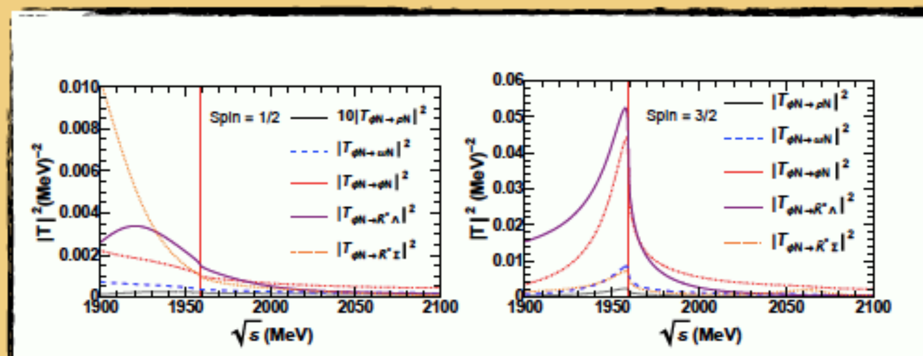
- Correlation functions of two hadrons: femtoscopy

$$C_{\phi N}(k) \;=\; \frac{1}{3}C^{(\frac{1}{2})}_{\phi N}(k) + \frac{2}{3}C^{(\frac{3}{2})}_{\phi N}(k)$$



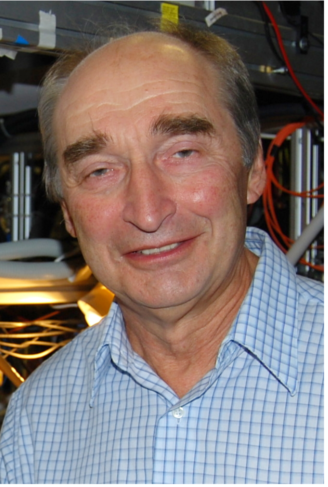
Data points : S. Acharya, et al., Alice collaboration, Phys. Rev. Lett. 127, 172301 (2021)

Coupled channel analysis for ϕN: correlation function cannot distinguish the existence or not of a ϕN quasi-bound state



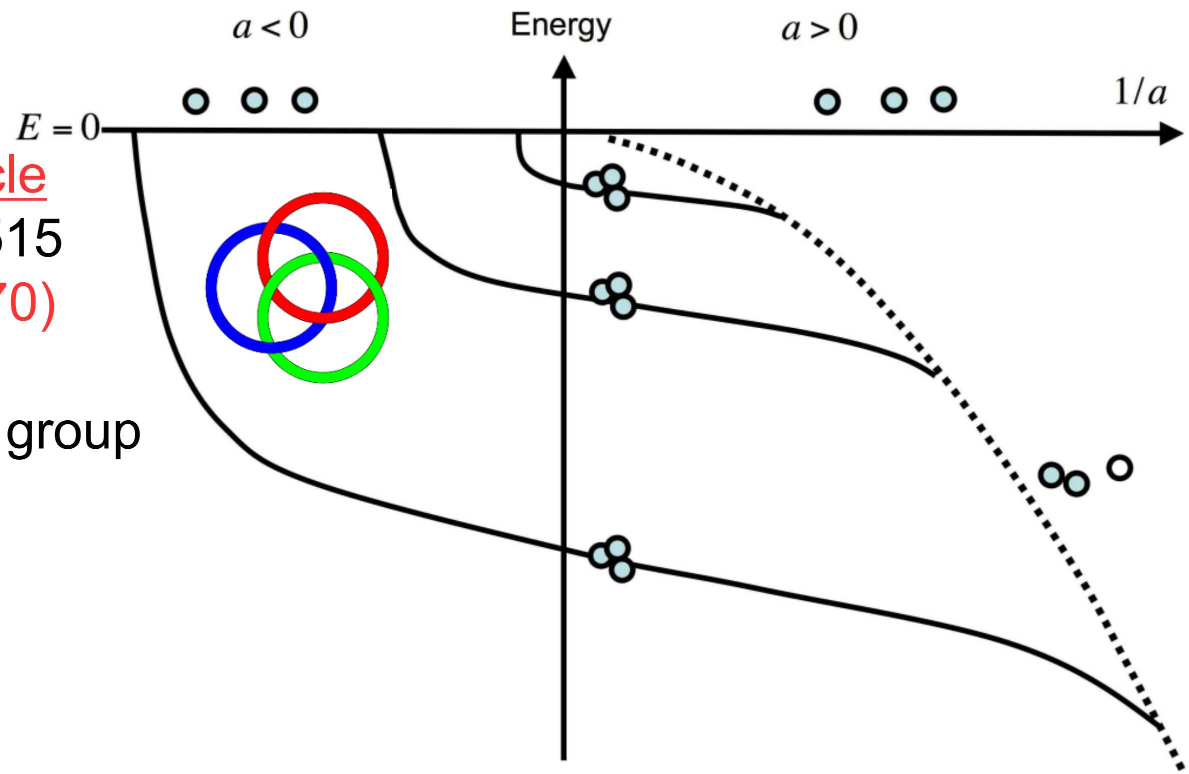
Abreu, Gubler, Khemchandani, Martínez Torres, Hosaka, submitted to Phys. Lett. B (arXiv: 2409.05170v1)

Física dos estados de Efimov (Renato Higa)



Efimov effect

PLB 33, 563 (1970)



- RG-flow towards a limit-cycle
- Efimov states: $E^{(n+1)}/E^{(n)}$ ~ 515
- V. Efimov, PLB33, 563 (1970)
- Ahrus group
- ITA-UNESP-UNICMP-UFF group
- Seattle group
- Purdue-Colorado group
- ...

Bhaduri et al., Am.J.Phys. 79, 274 (2011)

GRAFITE USP

Hypernucleus: Λnn

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Search for evidence of $^{3}_{\Lambda}n$ by observing $d+\pi^-$ and $t+\pi^-$ final states in the reaction of ^{6}Li+^{12}C at $2A$ GeV

C. Rappold *et al.* (HypHI Collaboration)

Phys. Rev. C **88**, 041001(R) – Published 10 October 2013

Article | References | Citing Articles (67) | PDF | HTML | Export Citation

ABSTRACT

The experimental data obtained from the reaction of ^{6}Li projectiles at $2A$ GeV on a fixed graphite target were analyzed to study the invariant mass distributions of $d+\pi^-$ and $t+\pi^-$. Indications of a signal in the $d+\pi^-$ and $t+\pi^-$ invariant mass distributions were observed with significances of 5.3 σ and 5.0 σ, respectively, when including the production target, and 3.7 σ and 5.2 σ, respectively, when excluding the target. The estimated mean values of the invariant mass for $d+\pi^-$ and $t+\pi^-$ signal were 2059.3 $\pm$ 1.3 $\pm$ 1.7 MeV/c^2 and 2993.7 $\pm$ 1.3 $\pm$ 0.6 MeV/c^2 respectively. The lifetime estimation of the possible bound states yielding to $d+\pi^-$ and $t+\pi^-$ final states were deduced to be as $181^{+30}_{-24}\pm 25$ ps and $190^{+47}_{-35}\pm 36$ ps, respectively. Those final states may be interpreted as the two-body and three-body decay modes of a neutral bound state of two neutrons and a Λ hyperon, $^{3}_{\Lambda}n$.

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Spectroscopic study of a possible Λnn resonance and a pair of ΣNN states using the $(e,e'K^+)$ reaction with a tritium target

B. Pandey *et al.* (Hall A Collaboration)

Phys. Rev. C **105**, L051001 – Published 20 May 2022

Article | References | No Citing Articles | PDF | HTML | Export Citation

ABSTRACT

A mass spectroscopy experiment with a pair of nearly identical high-resolution spectrometers and a tritium target was performed in Hall A at Jefferson Lab. Utilizing the $(e,e'K^+)$ reaction, enhancements, which may correspond to a possible Λnn resonance and a pair of ΣNN states, were observed with an energy resolution of about 1.21 MeV (σ), although greater statistics are needed to make definitive identifications. An experimentally measured Λnn state may provide a unique constraint in determining the Λn interaction, for which no scattering data exist. In addition, although bound $A=3$ and 4 Σ hypernuclei have been predicted, only an $A=4$ Σ hypernucleus ($^4_\Sigma$He) was found, utilizing the (K^-,π^-) reaction on a ^{4}He target. The possible bound ΣNN state is likely a $\Sigma^0 nn$ state, although this has to be confirmed by future experiments.

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Perspective | Published: 14 September 2021

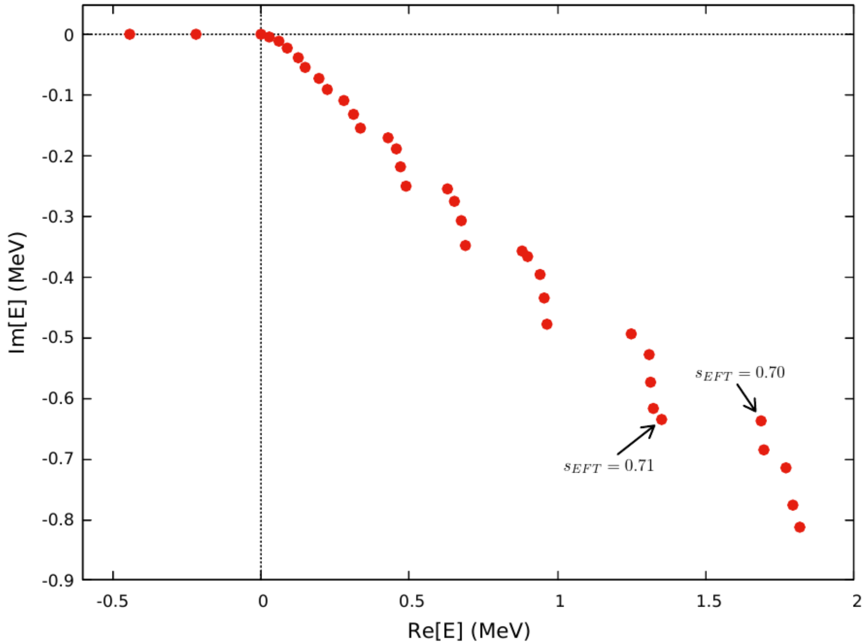
New directions in hypernuclear physics

Takehiko R. Saito, Wenbou Dou, Vasyl Drozd, Hiroyuki Ekawa, Samuel Escrig, Yan He, Nasser Kalantar-Nayestanaki, Ayumi Kasagi, Myroslav Kavatsyuk, Enqiang Liu, Yue Ma, Shizu Minami, Abdul Muneem, Manami Nakagawa, Kazuma Nakazawa, Christophe Rappold, Nami Saito, Christoph Scheidenberger Masato Taki, Yoshiki K. Tanaka, Junya Yoshida, Masahiro Yoshimoto, He Wang & Xiaohon

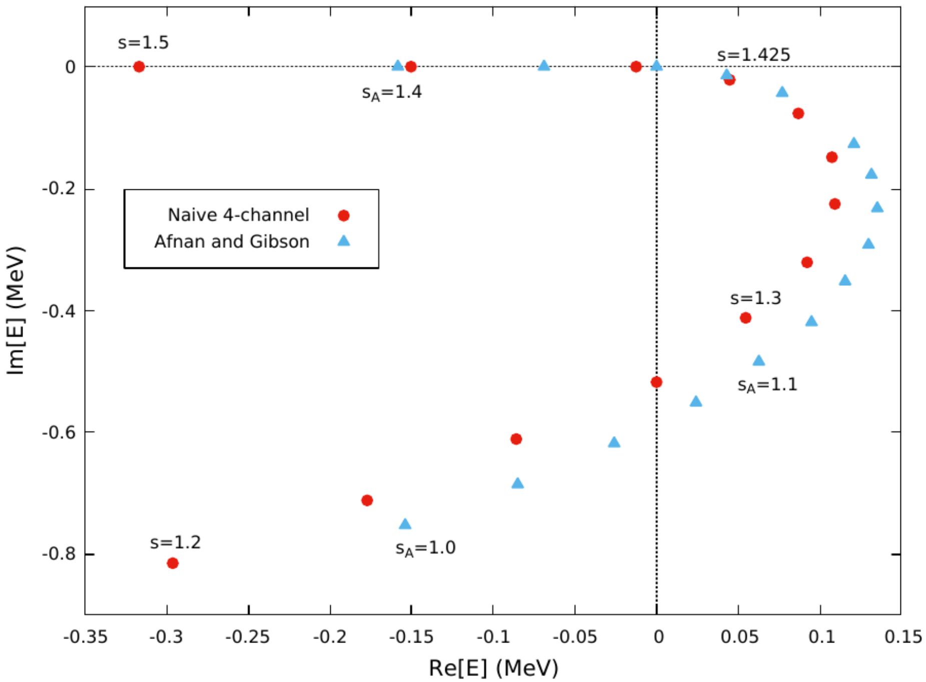
Nature Reviews Physics 3, 803–813 (2021) | Cite this article

Breno A. Garcia, MSc. thesis

Hypernucleus: Λnn



EFT

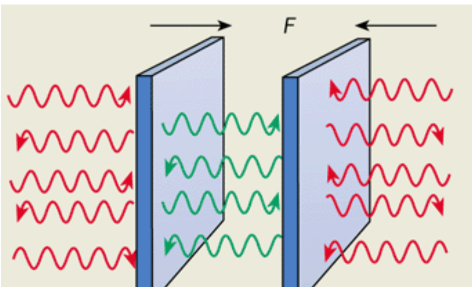


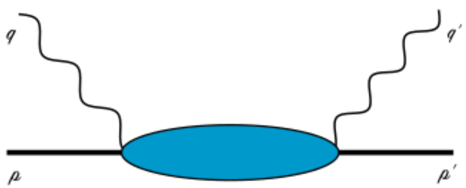
Separable potential

Breno A. Garcia, MSc. thesis

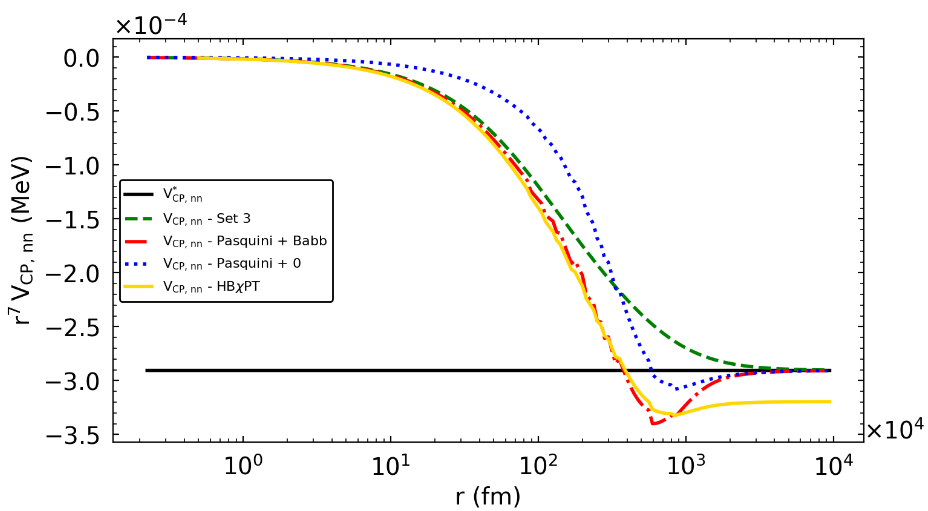
Casimir-Polder forces btw two neutrons

Hagelstein, et al., PPNPhys. 88, 29 (2016)





Babb, RH, Hussein, EPJA 53, 126 (2017)



F. Hagelstein et al. / Progress in Particle and Nuclear Physics 88 (2016) 29–97 33

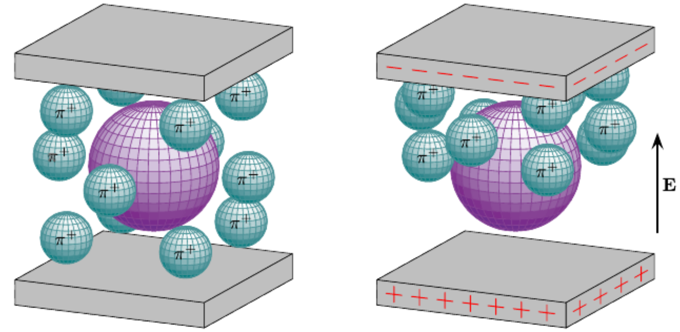
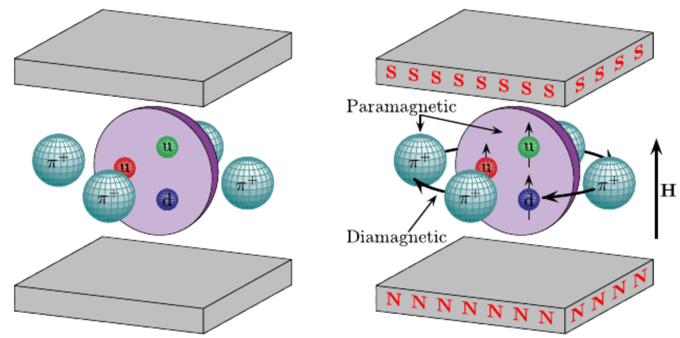


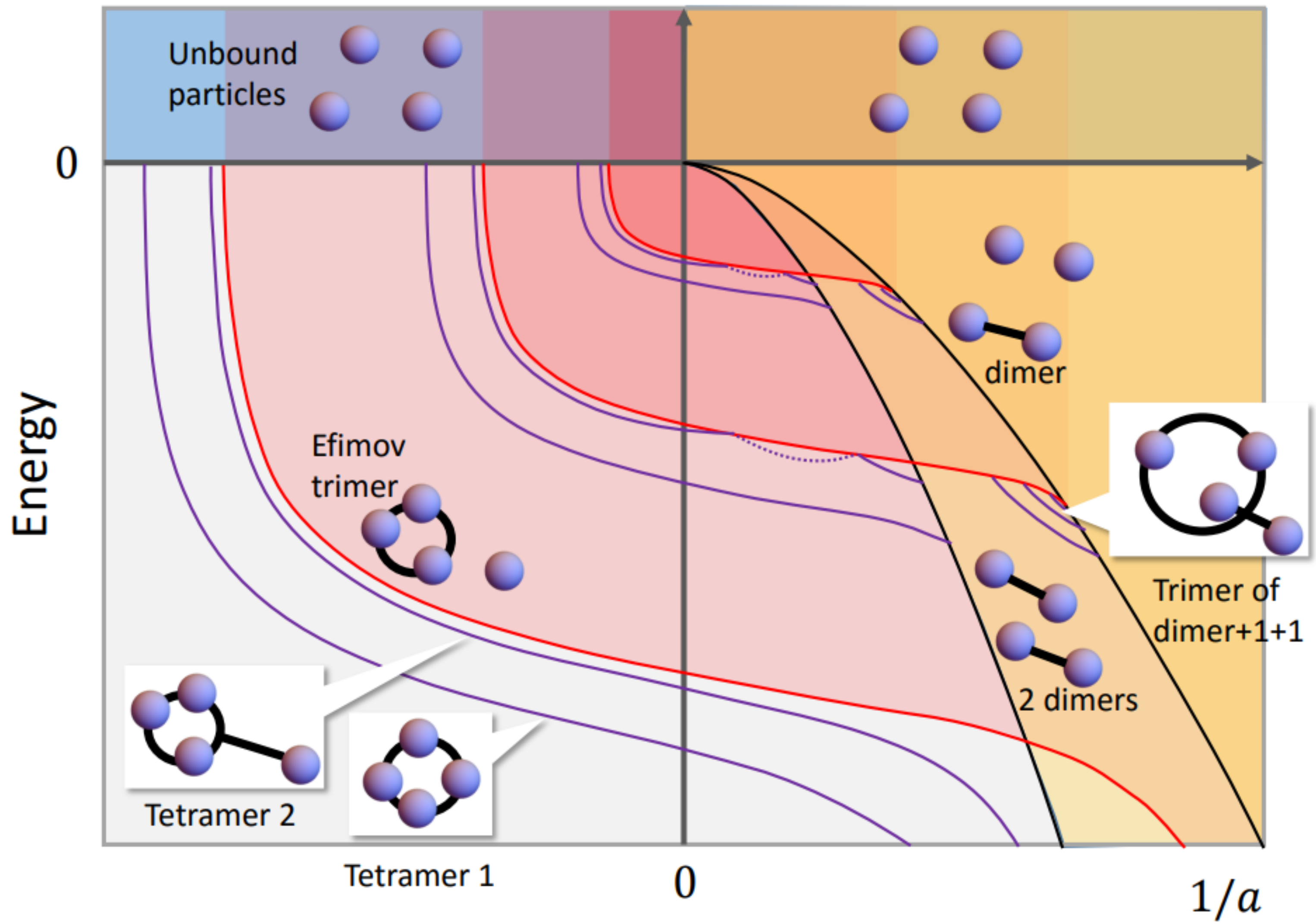
Fig. 2.1. Naive view of the proton, consisting of a pion cloud and a quark core, placed between the plates of a parallel plate capacitor. The left (right) figure shows the capacitor discharged (charged).
Source: Plot courtesy of Phil Martel.



Naive view of the proton, consisting of a pion cloud and a quark core, placed between the poles of a magnet. The left (right) figure shows the magnetic field turned off (on).
lot courtesy of Phil Martel.

Relevance to UCN physics
M. S. Godoy's MSc. Thesis

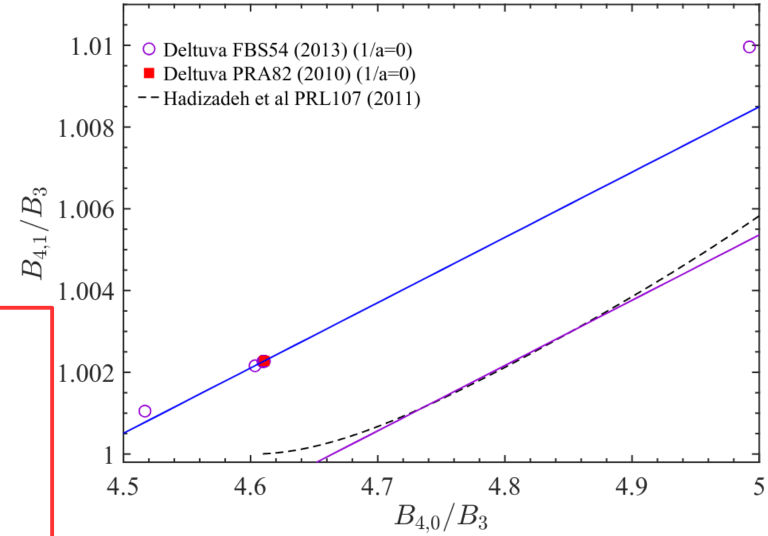
Universality: four bosons

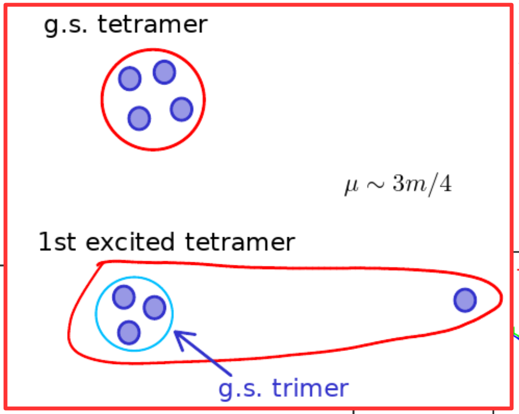


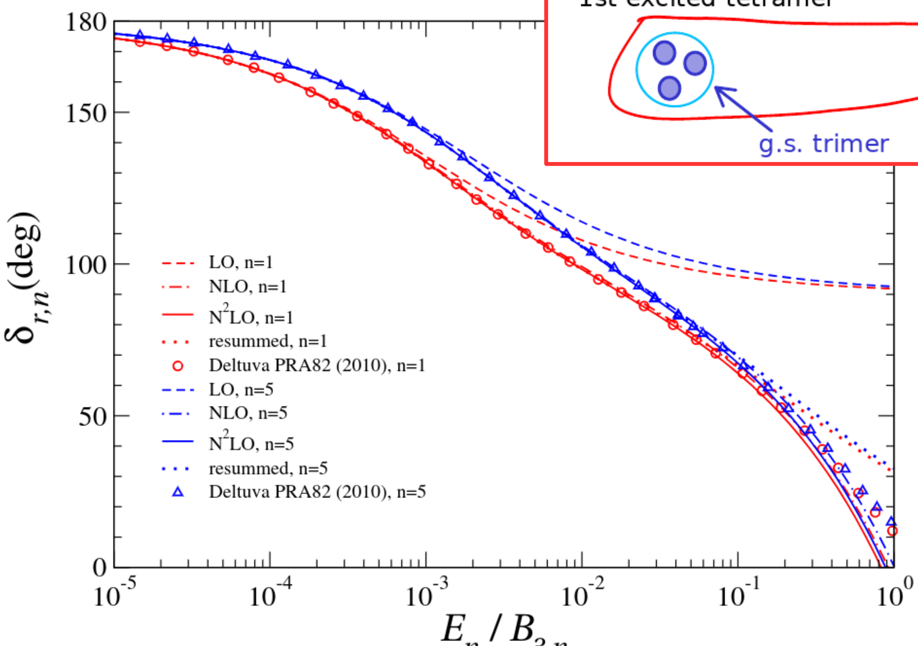
Naidon, Endo, Rep.Prog.Phys. 80, 056001 (2017)

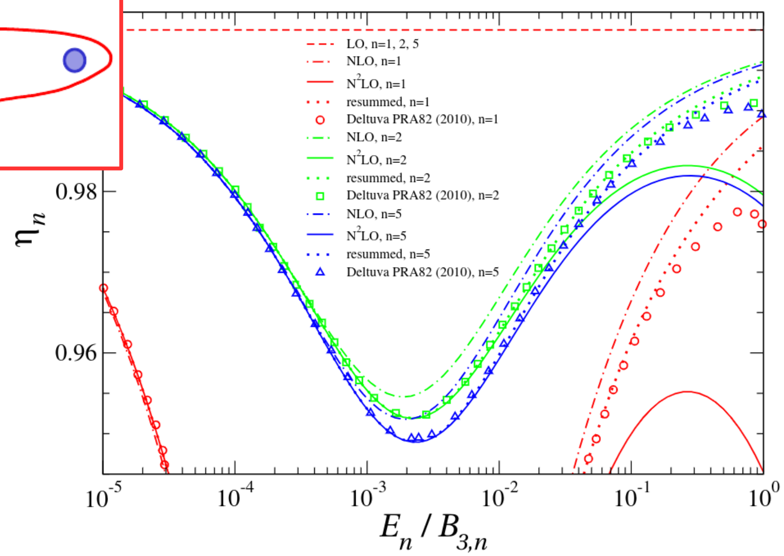
EFT and universality of SRI

- Importance of 4BF: NLO
- Excited 4Bsyst: halo structure
- Predictions for boson-trimer obs.
- F. Wu, T.Frederico, RH, U.van Kolck
- (PRA109, 043301)









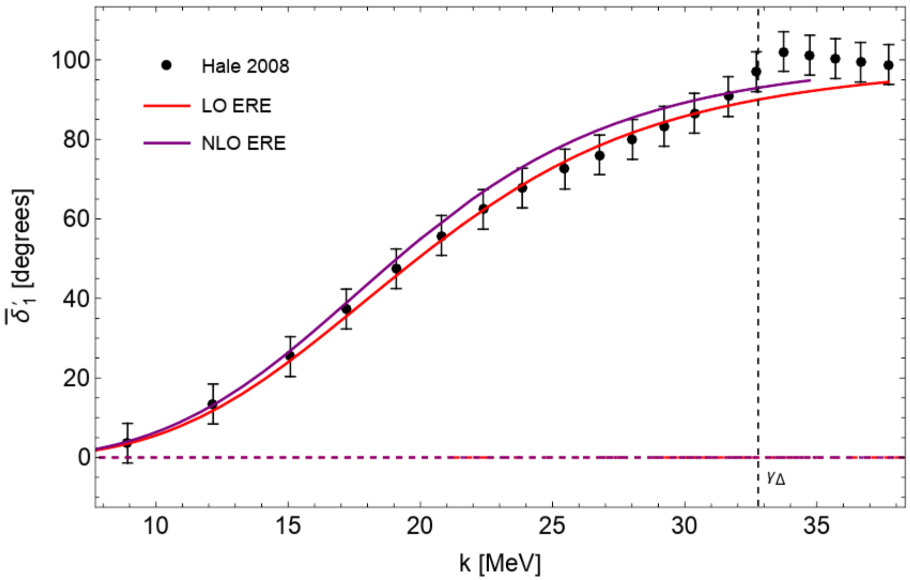
$1^{\underline{st}}$ excited ^4He nucleus: Halo EFT approach

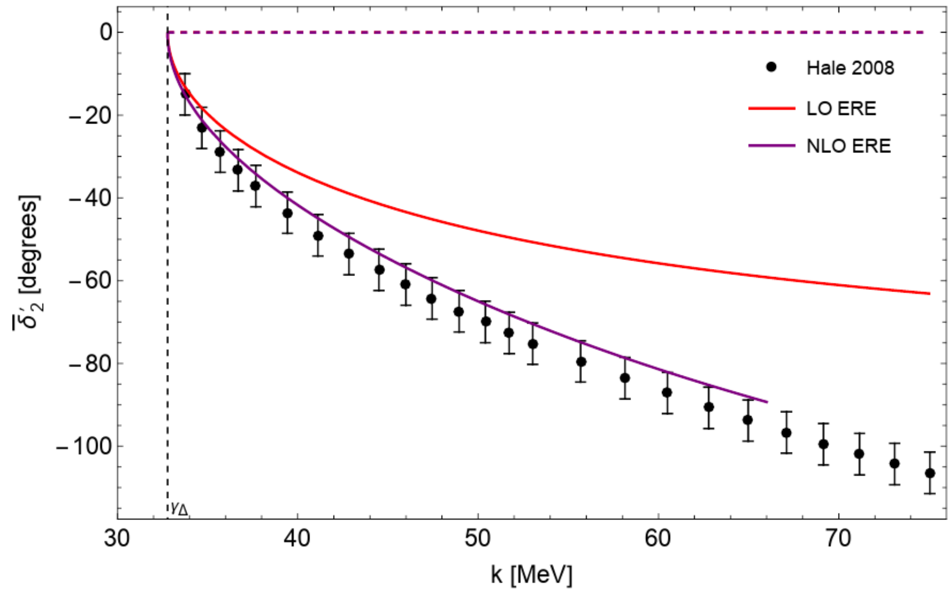
resonant state between $p-\ ^3H$ and $n-\ ^3He$

coupled-channel problem

ATOMKI anomaly: $X(16)$ boson

Matheus F. Cichocki, IC project: X(3872)

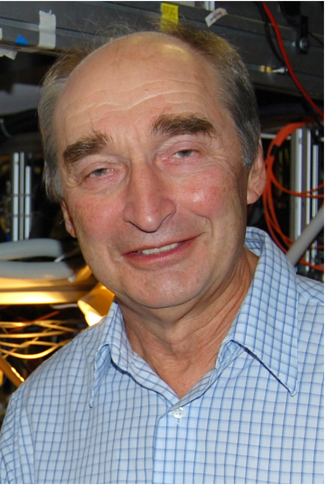




$$E_R \approx 0.127\text{MeV};\ \ \Gamma_R \approx 0.288\text{MeV}$$

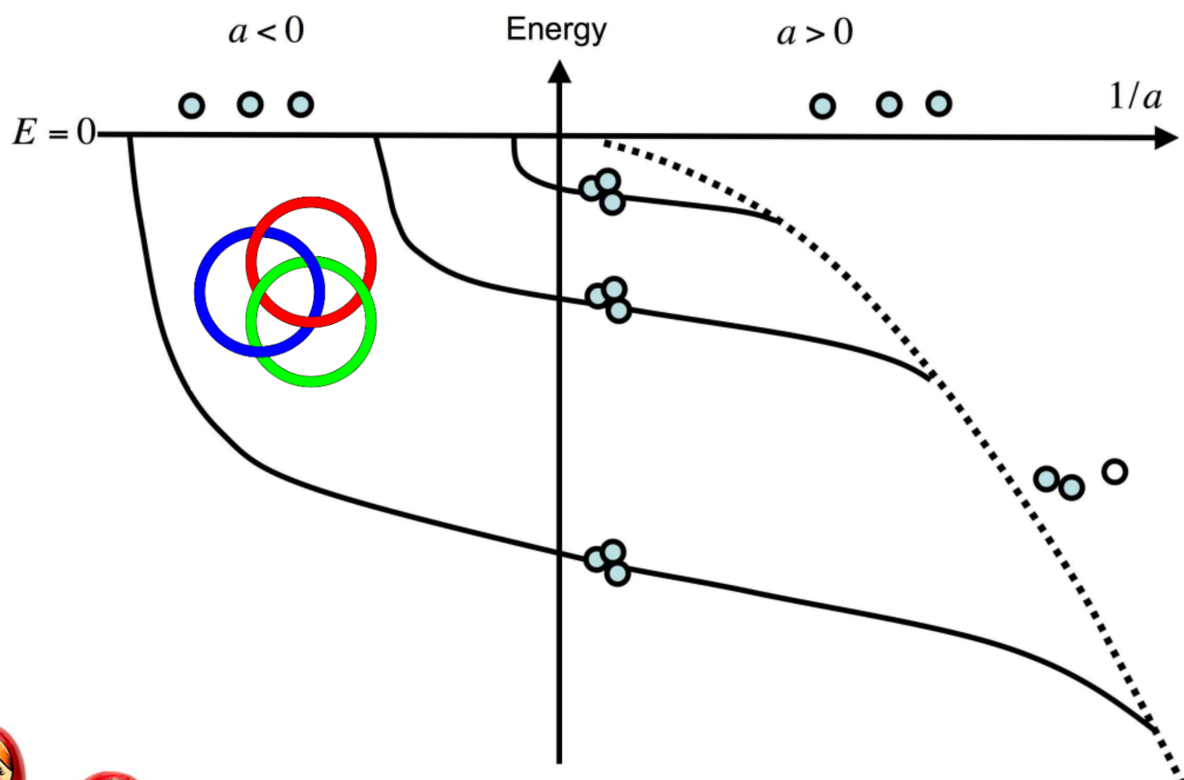
Vinícius B. B. Ader, PhD. project

FIM



Efimov effect

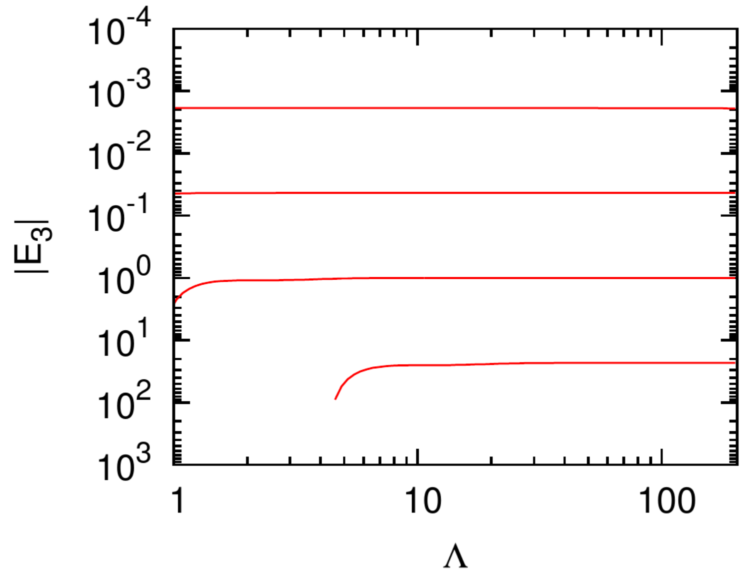
PLB 33, 563 (1970)

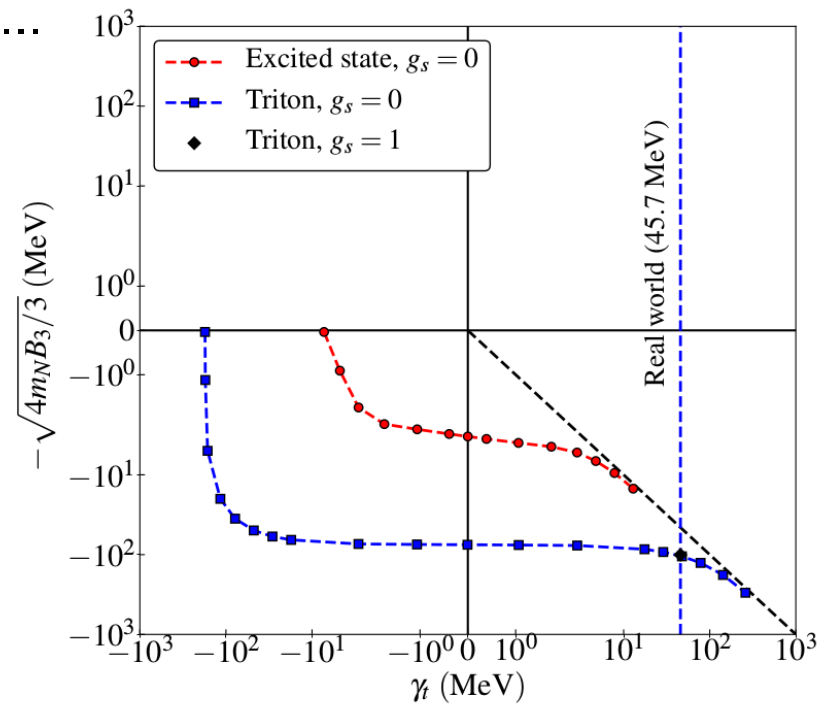


Bhaduri et al., Am.J.Phys. 79, 274 (2011)

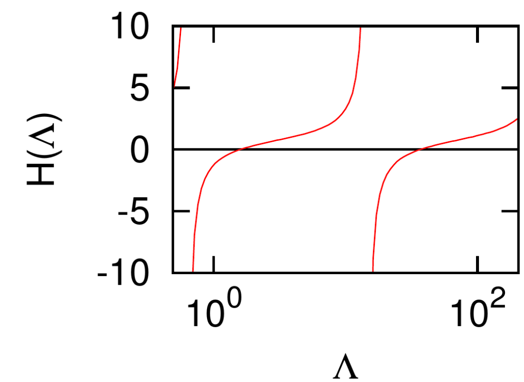
EFT and universality of SRI

- RG-flow towards a limit-cycle
- Efimov states: $E^{(n+1)}/E^{(n)}$ ~ 515
- V. Efimov, PLB33, 563 (1970)
- Ahrus group
- ITA-UNESP-UNICMP-UFF group
- Seattle group
- Purdue-Colorado group
- ...





Hammer. RH



Rupak, Vaghani,
RH, van Kolck (2019)

Hypernucleus: Λnn

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Search for evidence of ${}^3_\Lambda n$ by observing $d + \pi^-$ and $t + \pi^-$ final states in the reaction of ^{6}Li+^{12}C at $2A$ GeV

C. Rappold *et al.* (HypHI Collaboration)
Phys. Rev. C **88**, 041001(R) – Published 10 October 2013

Article | References | Citing Articles (67) | PDF | HTML | Export Citation

ABSTRACT

The experimental data obtained from the reaction of ^{6}Li projectiles at $2A$ GeV on a fixed graphite target were analyzed to study the invariant mass distributions of $d + \pi^-$ and $t + \pi^-$. Indications of a signal in the $d + \pi^-$ and $t + \pi^-$ invariant mass distributions were observed with significances of 5.3 σ and 5.0 σ, respectively, when including the production target, and 3.7 σ and 5.2 σ, respectively, when excluding the target. The estimated mean values of the invariant mass for $d + \pi^-$ and $t + \pi^-$ signal were 2059.3 $\pm$ 1.3 $\pm$ 1.7 MeV/c^2 and 2993.7 $\pm$ 1.3 $\pm$ 0.6 MeV/c^2 respectively. The lifetime estimation of the possible bound states yielding to $d + \pi^-$ and $t + \pi^-$ final states were deduced to be as $181^{+30}_{-24} \pm 25$ ps and $190^{+47}_{-35} \pm 36$ ps, respectively. Those final states may be interpreted as the two-body and three-body decay modes of a neutral bound state of two neutrons and a Λ hyperon, ${}^3_\Lambda n$.

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Spectroscopic study of a possible Λnn resonance and a pair of ΣNN states using the $(e, e'K^+)$ reaction with a tritium target

B. Pandey *et al.* (Hall A Collaboration)
Phys. Rev. C **105**, L051001 – Published 20 May 2022

Article | References | No Citing Articles | PDF | HTML | Export Citation

ABSTRACT

A mass spectroscopy experiment with a pair of nearly identical high-resolution spectrometers and a tritium target was performed in Hall A at Jefferson Lab. Utilizing the $(e, e'K^+)$ reaction, enhancements, which may correspond to a possible Λnn resonance and a pair of ΣNN states, were observed with an energy resolution of about 1.21 MeV (σ), although greater statistics are needed to make definitive identifications. An experimentally measured Λnn state may provide a unique constraint in determining the Λn interaction, for which no scattering data exist. In addition, although bound $A = 3$ and 4 Σ hypernuclei have been predicted, only an $A = 4$ Σ hypernucleus (${}^4_\Sigma$He) was found, utilizing the (K^-, π^-) reaction on a ^{4}He target. The possible bound ΣNN state is likely a $\Sigma^0 nn$ state, although this has to be confirmed by future experiments.

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New directions in hypernuclear physics

Takehiko R. Saito, Wenbou Dou, Vasyl Drozd, Hiroyuki Ekawa, Samuel Escrig, Yan He, Nasser Kalantar-Nayestanaki, Ayumi Kasagi, Myroslav Kavatsyuk, Enqiang Liu, Yue Ma, Shizu Minami, Abdul Muneem, Manami Nakagawa, Kazuma Nakazawa, Christophe Rappold, Nami Saito, Christoph Scheidenberger, Masato Taki, Yoshiki K. Tanaka, Junya Yoshida, Masahiro Yoshimoto, He Wang & Xiaohon

Nature Reviews Physics 3, 803–813 (2021) | Cite this article

Breno A. Garcia, MSc. thesis

GRAPHITE

Hypernucleus: Λnn

$$a_{nn} = -18.9 \pm 0.4 \text{ fm}, \quad r_{nn} = 2.75 \pm 0.11 \text{ fm}$$

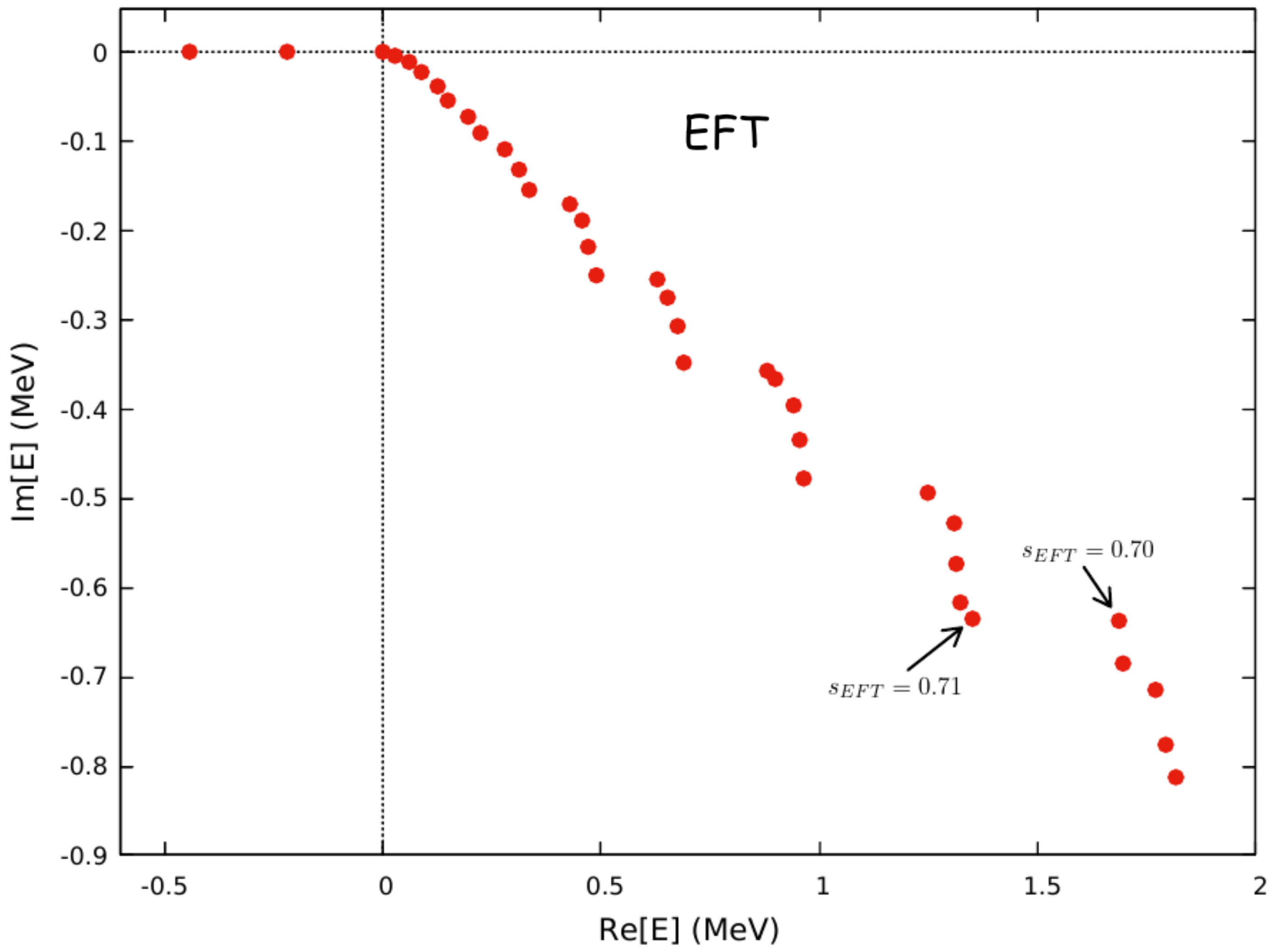
Nijmegen potential model D

	Λp	Λn
a_s	-1.77 ± 0.28	-2.03 ± 0.32
r_s	3.78 ± 0.35	3.66 ± 0.32
a_t	-2.06 ± 0.12	-1.84 ± 0.10
r_t	3.18 ± 0.12	3.32 ± 0.11

$$T_{\Lambda n} \Rightarrow s_{EFT} T_{\Lambda n}$$

Breno A. Garcia, MSc. thesis

Hypernucleus: Λnn



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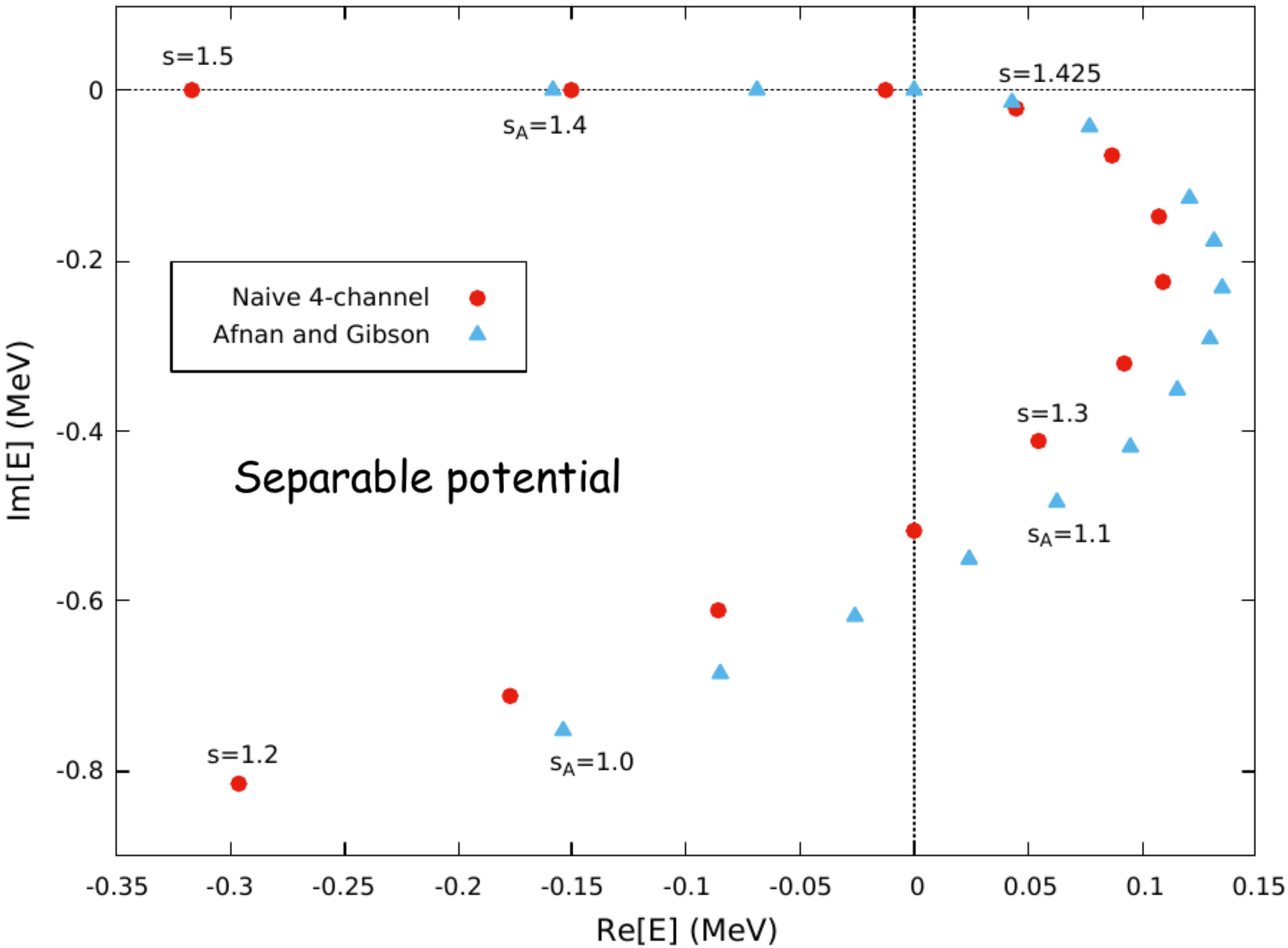
Hypernucleus: Λnn



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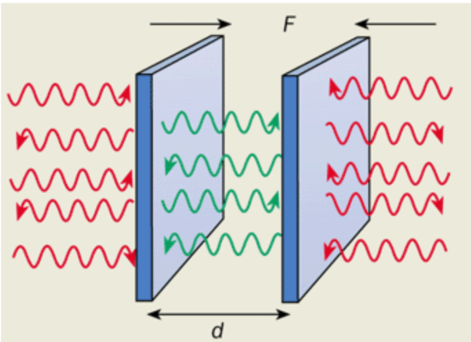
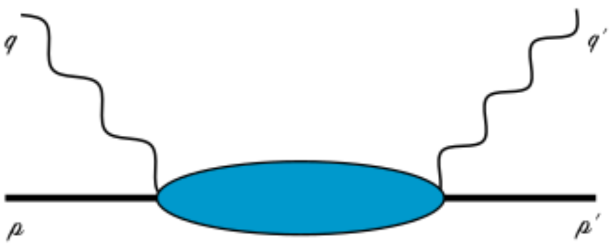
Casimir-Polder forces btw two neutrons





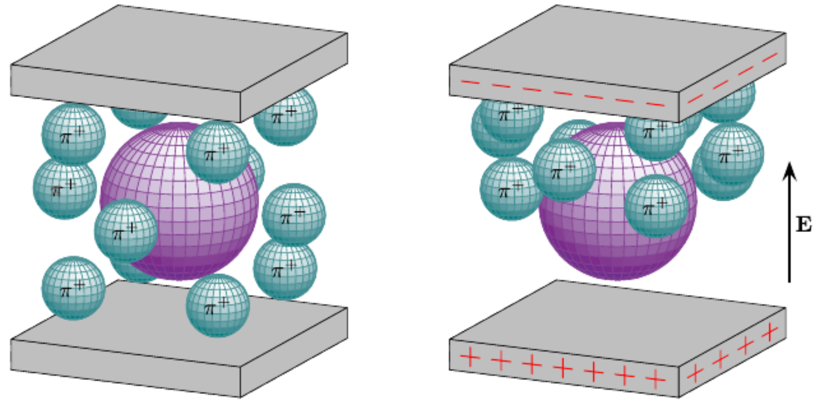


Fig. 2.1. Naive view of the proton, consisting of a pion cloud and a quark core, placed between the plates of a parallel plate capacitor. The left (right) figure shows the capacitor discharged (charged).
Source: Plot courtesy of Phil Martel.

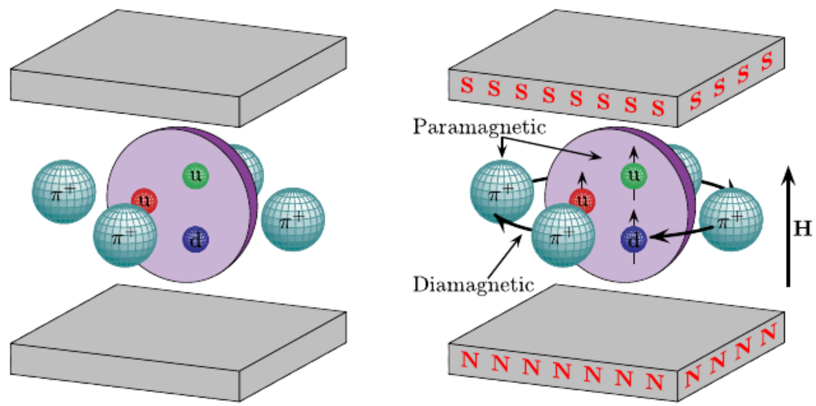
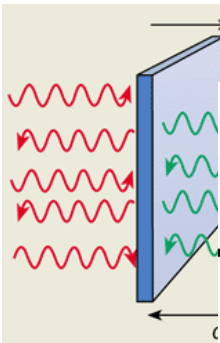


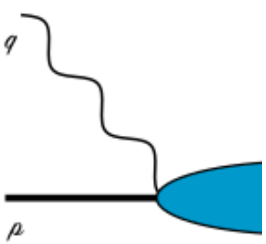
Fig. 2.2. Naive view of the proton, consisting of a pion cloud and a quark core, placed between the poles of a magnet. The left (right) figure shows the external magnetic field turned off (on).
Source: Plot courtesy of Phil Martel.

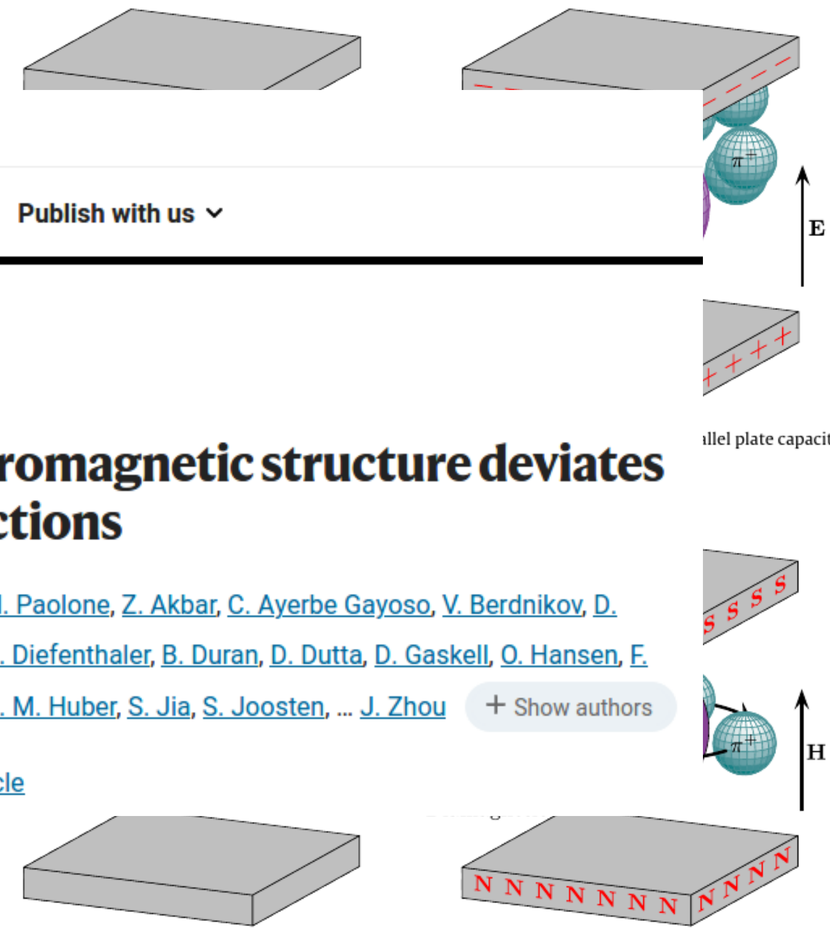
Hagelstein, et al., Prog.Part.Nucl.Phys. 88, 29 (2016)

Casimir-Polder forces btw two neutrons

F. Hagelstein et al. / Progress in Particle and Nuclear Physics 88 (2016) 29–97 33







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Article | Published: 19 October 2022

Measured proton electromagnetic structure deviates from theoretical predictions

R. Li, N. Sparveris, H. Atac, M. K. Jones, M. Paolone, Z. Akbar, C. Ayerbe Gayoso, V. Berdnikov, D. Biswas, M. Boer, A. Camsonne, J.-P. Chen, M. Diefenthaler, B. Duran, D. Dutta, D. Gaskell, O. Hansen, F. Hauenstein, N. Heinrich, W. Henry, T. Horn, G. M. Huber, S. Jia, S. Joosten, … J. Zhou + Show authors

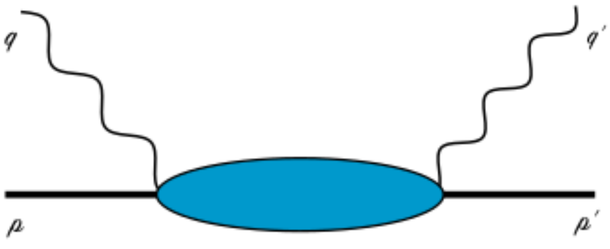
Nature **611**, 265–270 (2022) | Cite this article

…llel plate capacitor. The left (right) figure

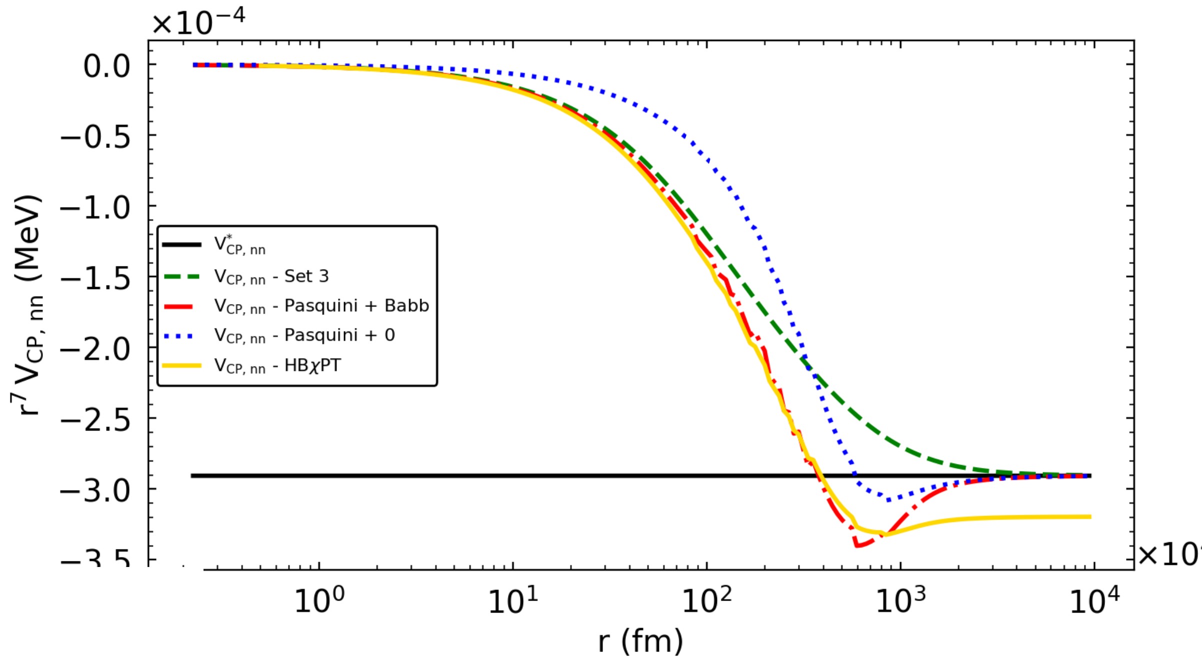
Fig. 2.2. Naive view of the proton, consisting of a pion cloud and a quark core, placed between the poles of a magnet. The left (right) figure shows the external magnetic field turned off (on).
Source: Plot courtesy of Phil Martel.

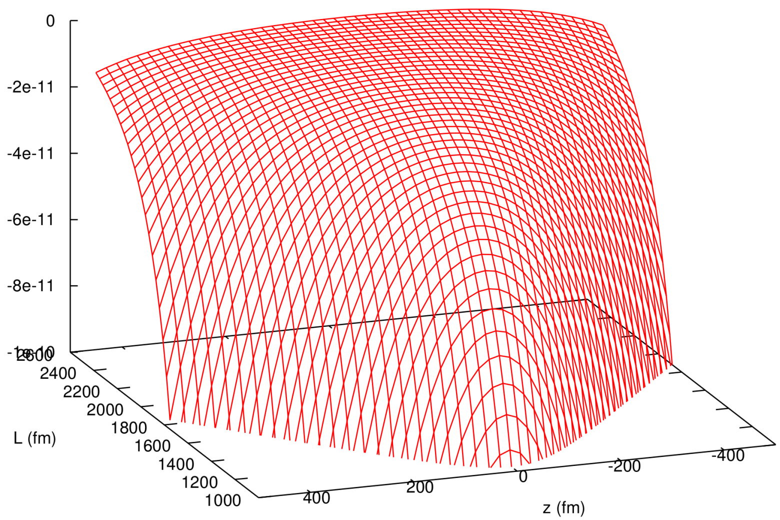
Hagelstein, et al., Prog.Part.Nucl.Phys. 88, 29 (2016)

Casimir-Polder forces btw two neutrons



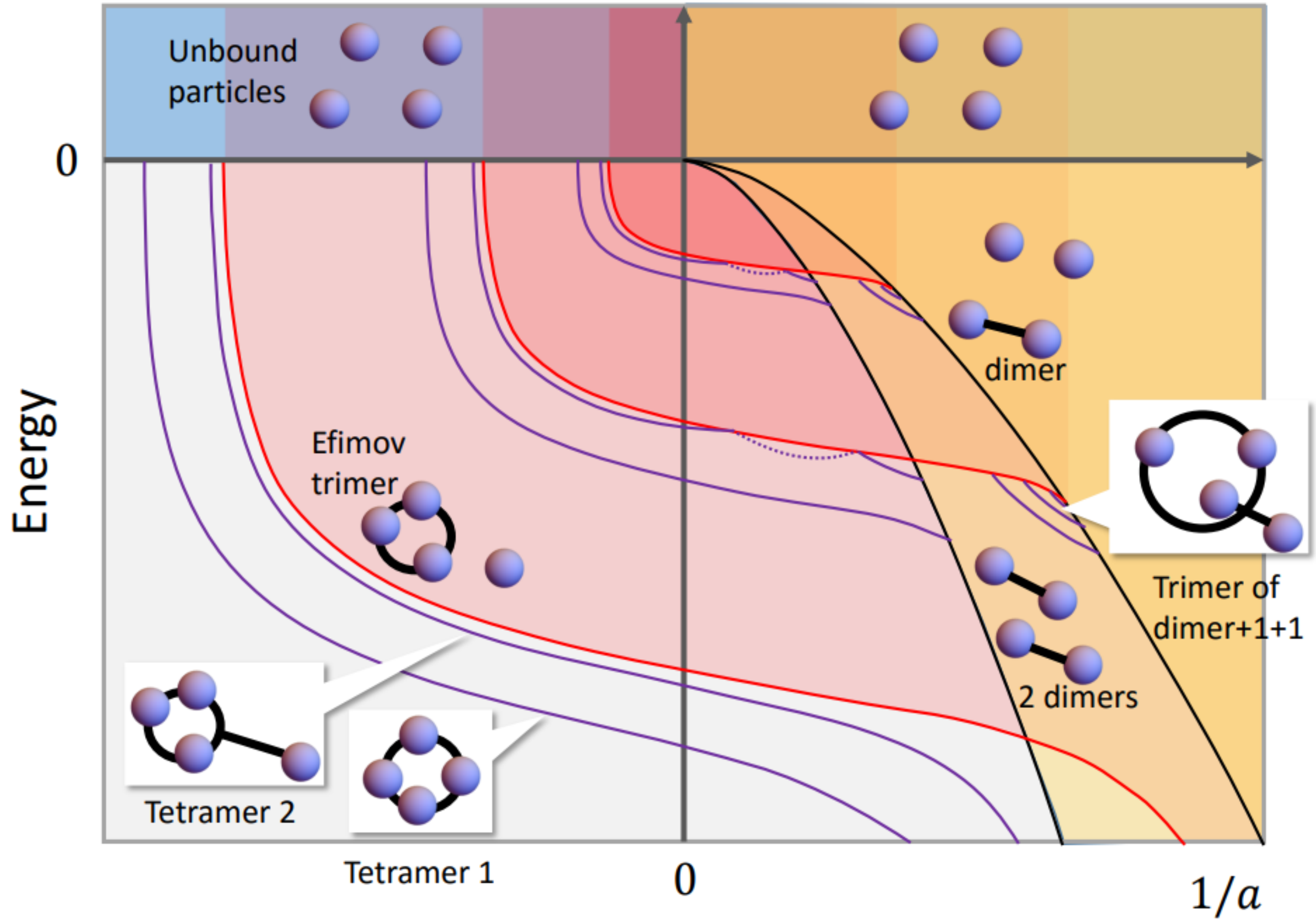
Relevance to UCN physics
M. S. Godoy's MSc. Thesis





Babb, RH, Hussein, EPJA 53, 126 (2017)

Universality: four bosons



Naidon, Endo, Rep.Prog.Phys. 80, 056001 (2017)

Universality: four bosons

Controversy: 4B parameter necessary?

- Yes – Adhikari et al., PRL 74, 487 (1995), Yamashita et al., EurPhysLett 75, 555 (2006), Hadizadeh et al., PRL 107, 135304 (2011)

- No – Hammer, Platter, EPJA 32, 113 (2007), von Stecher et al., Nature Phys. 5, 417 (2009)

- EFT – 4B param. Is a NLO effect
- Bazak et al., PRL 122, 143001 (2019)
- Wu, Frederico, RH, van Kolck, PRA 109, 043301 (2024)

Energy correlations

$$\text{LO:}\begin{cases} B^{(0)}_{4,0} = \kappa_0 B_3, \\ B^{(0)}_{4,1} = \kappa_1 B_3, \end{cases} \Rightarrow \quad B^{(0)}_{4,1} = \frac{\kappa_1}{\kappa_0} B^{(0)}_{4,0},$$

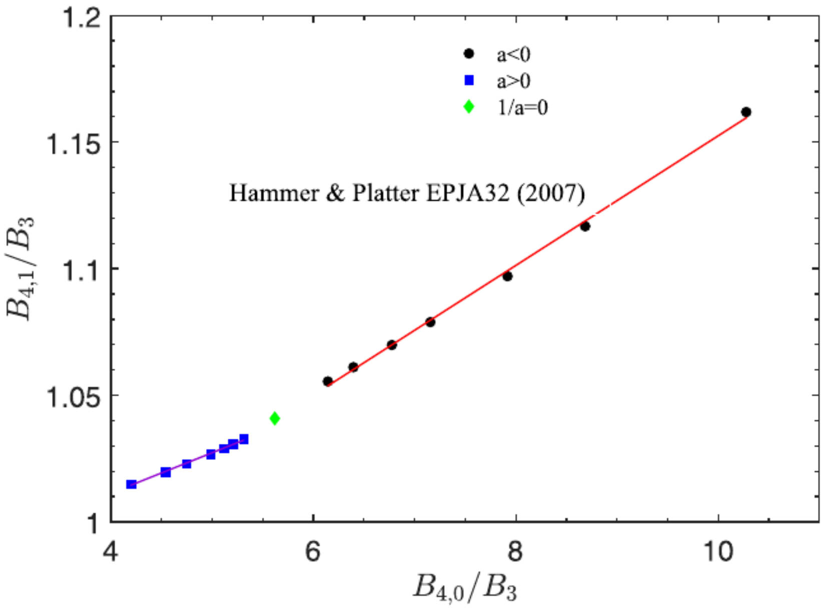
$$\begin{cases} \dfrac{\Gamma^{(0)}_{4,0}}{2} = \gamma_0 B_3 = \dfrac{\gamma_0}{\kappa_0} B^{(0)}_{4,0}, \\ \dfrac{\Gamma^{(0)}_{4,1}}{2} = \gamma_1 B_3 = \dfrac{\gamma_1}{\kappa_0} B^{(0)}_{4,0}, \end{cases}$$

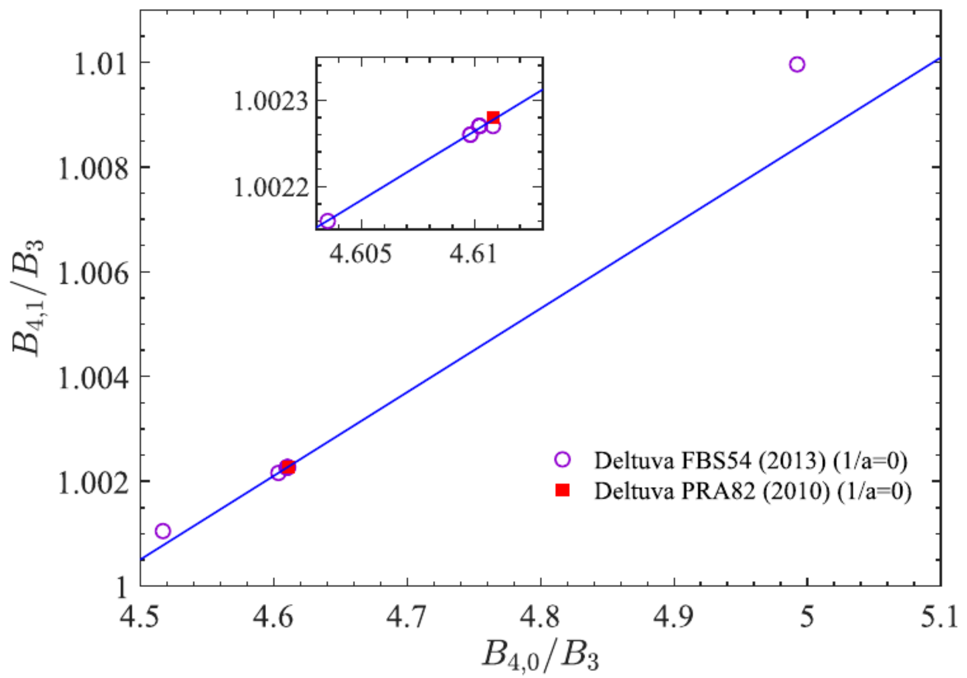
Energy correlations

$$\text{LO:} \begin{cases} B_{4,0}^{(0)} = \kappa_0 B_3, \\ B_{4,1}^{(0)} = \kappa_1 B_3, \end{cases} \Rightarrow \quad B_{4,1}^{(0)} = \frac{\kappa_1}{\kappa_0} B_{4,0}^{(0)},$$

$$\text{NLO:} \ \frac{B_{4,0}^{(1)}}{B_3} = \kappa_1 - \frac{\lambda_1}{\lambda_0}\kappa_0 + \frac{\lambda_1}{\lambda_0}\frac{B_{4,0}^{(1)}}{B_3} + \left(\frac{\eta_1}{\eta_0} - \frac{\lambda_1}{\lambda_0}\right)\eta_0\left(a_2\sqrt{mB_3}\right)^{-1} + zr_2\sqrt{mB_3}$$

Energy correlations





$$\frac{B_{4,0}^{(1)}}{B_3}$$

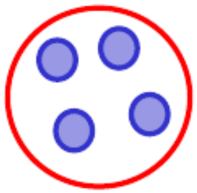
$$\frac{B_{4,0}^{(1)}}{B_3}$$

$$\frac{B_{4,0}^{(1)}}{B_3}$$

$$\frac{\lambda_1}{\lambda_0}$$

$1^{\underline{st}}$ excited tetramer: Halo EFT approach

g.s. tetramer



$$k_{g.s.} \sim \sqrt{2\mu(B_{4,0} - B_3)} \sim \sqrt{(\kappa_0 - 1)2\mu B_3} > \sqrt{2\mu B_3} \sim \frac{3}{2} M_{hi}^{\text{halo}}$$

$$\mu \sim 3m/4$$

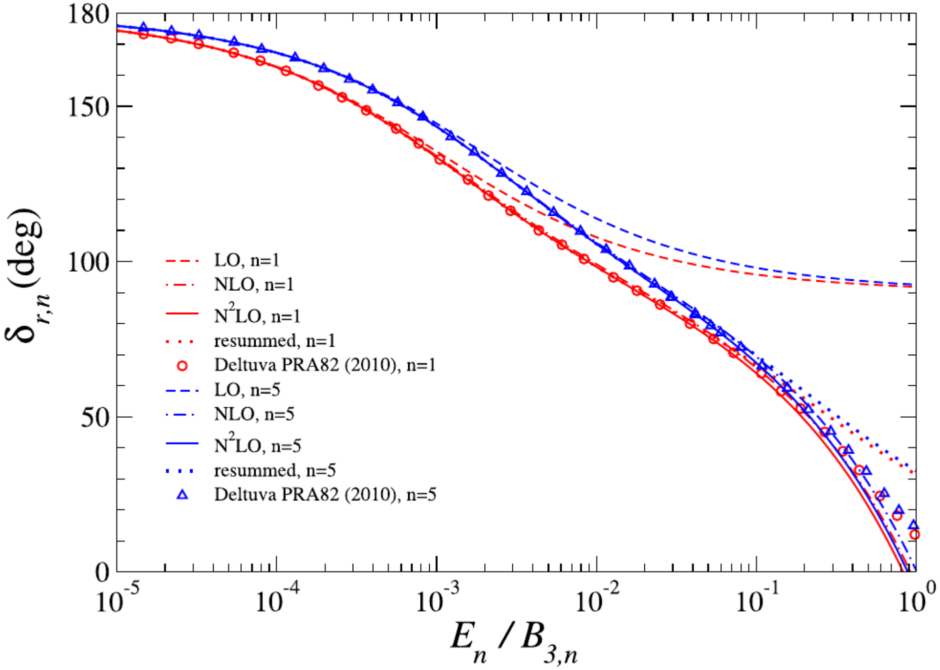
1st excited tetramer

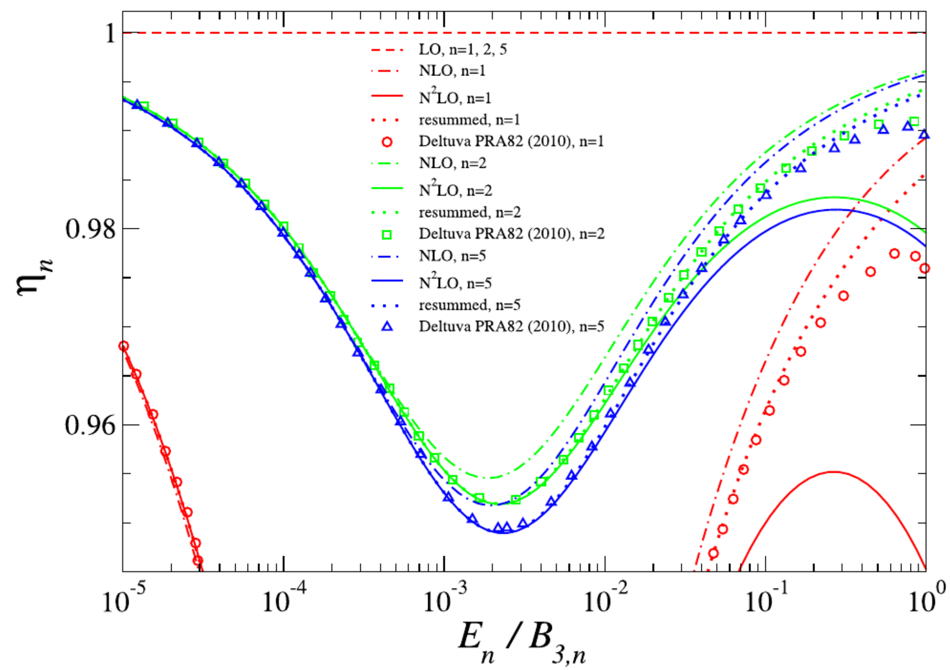
g.s. trimer

$$k_{1st\ ex.} \sim M_{lo}^{\text{halo}} \sim \sqrt{2\mu(B_{4,1} - B_3)} \sim \sqrt{(\kappa_1 - 1)2\mu B_3}$$

$$\frac{k_{1st.ex.}}{k_{g.s.}} \ll 1$$

$1^{\underline{st}}$ excited tetramer: Halo EFT approach





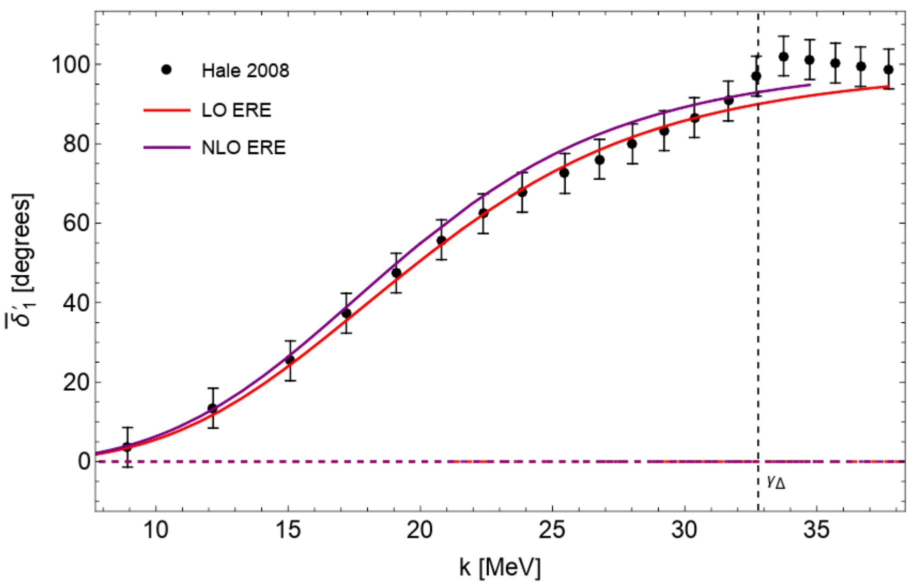
$$m(B_{4,1}-B_3)\langle r^2\rangle = \frac{1}{16}\left[1+\frac{r_0}{a_0}+3\frac{r_0^2}{2}a_0^2+\ldots+\langle r_C^2\rangle\right]$$
$$\approx 0.0625+0.0175+0.0074+\ldots\approx 0.0901$$

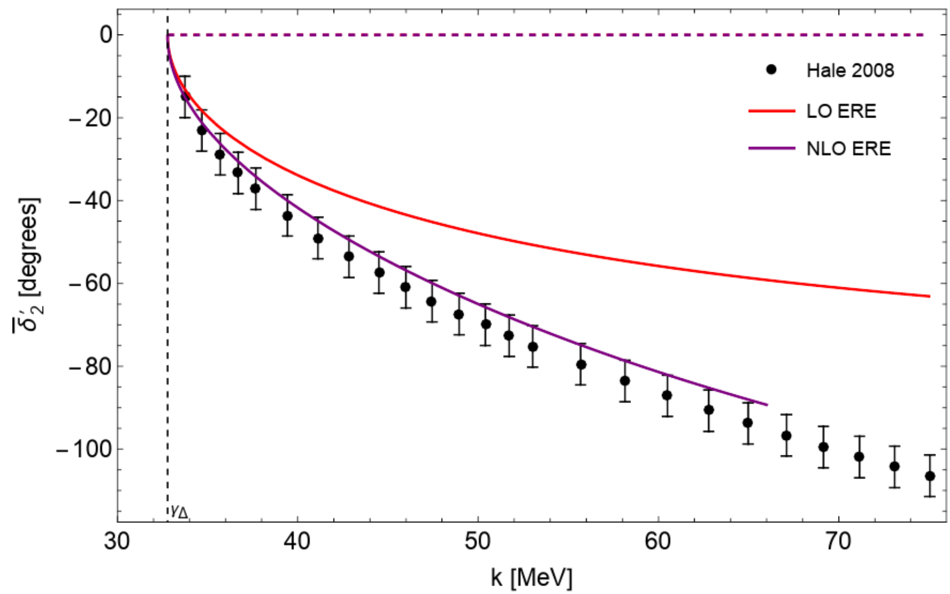
Hiyama-Kamimura: 0.0851

corrected $\langle r_C^2\rangle$:

1st excited ^{4}He nucleus: Halo EFT approach

resonant state between $p-{}^3$H and $n-{}^3$He
coupled-channel problem
ATOMKI anomaly: $X(16)$ boson





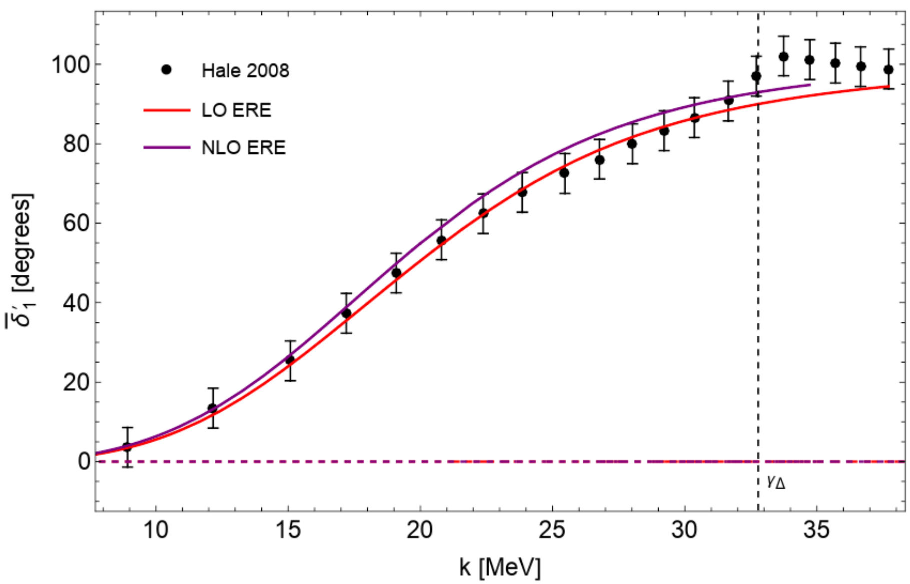
$$E_R \approx 0.127\text{MeV};\ \Gamma_R \approx 0.288\text{MeV}$$

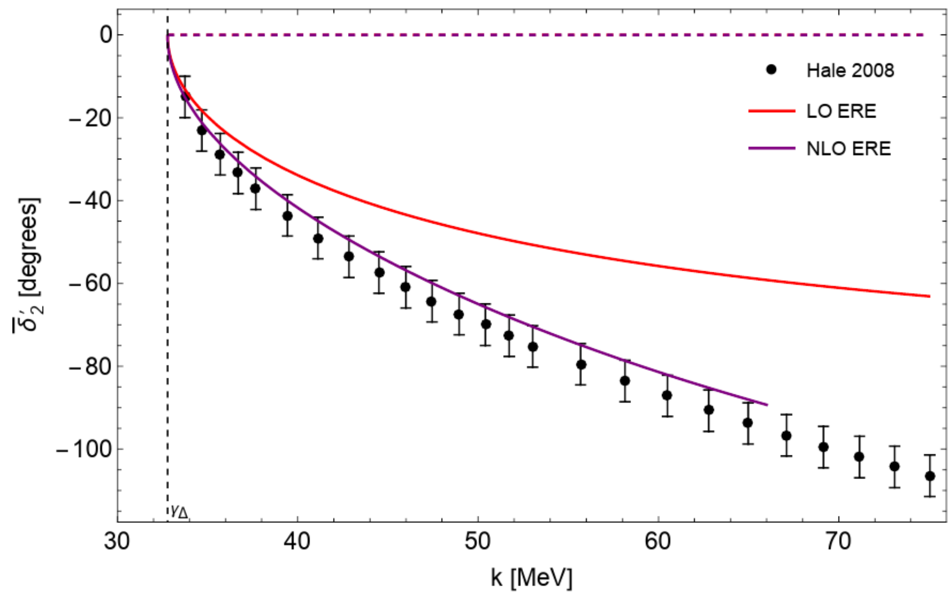
Vinícius B. B. Ader, PhD. project

1st excited ^{4}He nucleus: Halo EFT approach

resonant state between $p-\ ^3$H and $n-\ ^3$He
coupled-channel problem
ATOMKI anomaly: $X(16)$ boson

Matheus F. Cichocki, IC project: X(3872)





$$E_R \approx 0.127\text{MeV};\quad \Gamma_R \approx 0.288\text{MeV}$$

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