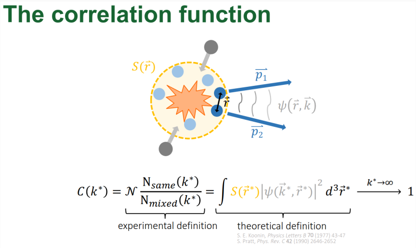
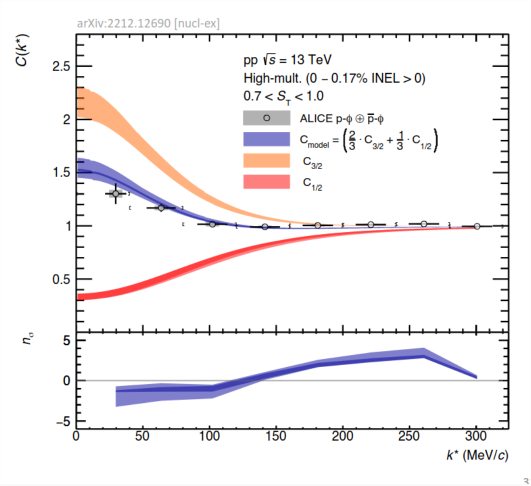
Wrap-up session / Thursday

July 7, 2023

EMMI Workshop: Bound states and particle interactions in the 21st century, July 3 – 6, 2023, Trieste, Italy

Proton-phi bound state
Raffaele Del Grande



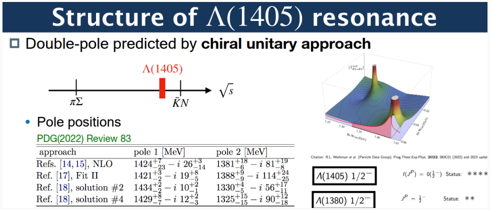


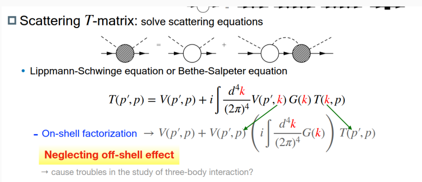
- existence of a $\phi - p$ bound state debated for decades
- ALICE@TUM: not an invariant-mass measurement of decay products but correlations between ϕ and p

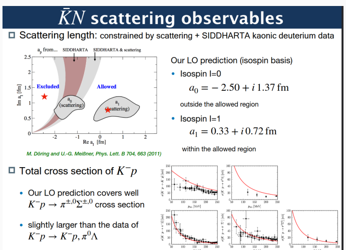
- $\phi - p$, 2 spin channels
- $V(S = 3/2)$ taken from HALQCD
- Supplemented by a phenomenological complex $V(S = 1/2)$ to describe the data
- Evidence for a bound state

Meson-baryon scattering and $\Lambda(1405)$ in baryon χPT

Xiu-Lei Ren

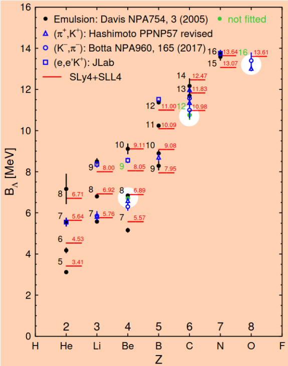






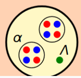
- Renormalizable, unified method for meson-baryon and baryon-baryon SU(3) χEFT
- Off-shell effects fully included
- Results consistent with some of the previous studies

Calculations of the structure of hypernuclei
Hans-Josef Schulze

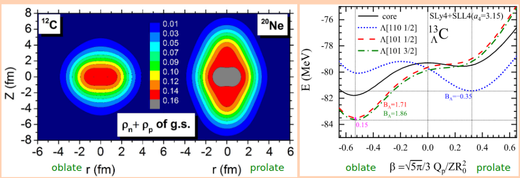


Results: Light Single-Λ Hypernuclei:

- Reasonable fit with $\langle \Delta B_\Lambda \rangle_{rms} \approx 0.32$ MeV
- Exceptions:
  overbound $^{16}_{\Lambda}$O ?
  corrected $^{12}_{\Lambda}$C ?
  cluster nucleus $^{9}_{\Lambda}$Be :
  large $\langle R_N^2 \rangle \rightarrow$ low ρ_N
  $\rightarrow$ low $V_\Lambda \rightarrow$ low B_Λ



More Sophistication: Deformation and Spin-Orbit Splitting:



- Core deformation lowers g.s. energy and splits the Λ s.p. levels, in addition to an explicit ΛN spin-orbit force
- Exp. s.o. splitting in $^{13}_{\Lambda}$C: Kohri et al., PRC 65, 034607 (2002)
  $E(1p_{1/2}) - E(1p_{3/2}) = 0.152 \pm 0.054 \pm 0.036$ MeV

- Description of hypernuclei across the periodic table using Skyrme-Hartree-Fock mean-field approach
- Reasonable description of fairly light and heavy hypernuclei, except for clustering effects
- Only 4 parameters

- Extension of SHF to account for deformations
- Deformations affect the Λ s.p. energies $\sim$ 1 MeV
- Core deformation depends on the nuclear Skyrme force which is not well constrained

Calculations of Λnn, ${}^{3}_{\Lambda}\mathrm{H}^{*}(\frac{3}{2}^{+})$, , ${}^{3}_{\Lambda}\mathrm{H}^{*}(\frac{3}{2}^{+})$ and ${}^{4}_{\Lambda\Lambda}\mathrm{H}(1^{+})$, and $\Lambda\Lambda nn(0^{+})$ states within LO $\not\pi$EFT

Martin Schäfer

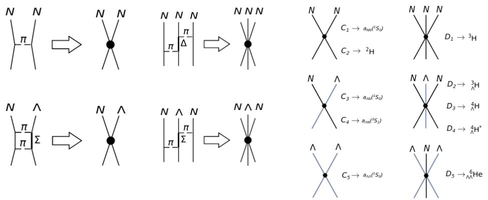
Hyper(nuclear) $\not\pi$EFT (introduced in Nir's talk)

Hamiltonian :

$$H_{\lambda}^{(\mathrm{LO})} = T_{\mathrm{k}} + V_2 + V_3 \qquad V_2 = \sum_{I,S} C_{\lambda}^{I,S} \sum_{i<j} \mathcal{P}_{ij}^{I,S} \delta_{\lambda}(\mathbf{r}_{ij})$$

$$V_3 = \sum_{I,S,\alpha} D_{\lambda,\alpha}^{I,S} \sum_{i<j<k} \mathcal{Q}_{ijk}^{I,S,\alpha} \sum_{\mathrm{cyc}} \delta_{\lambda}(\mathbf{r}_{ij})\delta_{\lambda}(\mathbf{r}_{jk})$$

Contact terms (minimal amount of parameters) $\rightarrow$ constrained by exp. data



$\rightarrow$ prediction of $\Lambda\mathrm{nn}$, $\Lambda\Lambda\mathrm{n}$, $\Lambda\Lambda\mathrm{nn}$, ${}^3_{\Lambda}\mathrm{H}^*$, ${}^5_{\Lambda}\mathrm{He}$, ${}^4_{\Lambda\Lambda}\mathrm{H}$, ${}^5_{\Lambda\Lambda}\mathrm{H}$, ${}^5_{\Lambda\Lambda}\mathrm{He}$

- Pionless EFT for hypernuclear few-body systems
- Focused on the lightest possible hypernuclear systems

$\Lambda\mathrm{nn}(\frac{1}{2}^{+})$ - **resonant state**

${}^3_{\Lambda}\mathrm{H}^*(\frac{3}{2}^{+})$ - **virtual state**

${}^4_{\Lambda\Lambda}\mathrm{H}(1^{+})$ - **weakly bound or virtual state** (preliminary)

$\Lambda\Lambda\mathrm{nn}(0^{+})$ - **narrow resonant state** (preliminary)

- Detailed and careful analysis and tracking of poles in the complex energy plane

Apiwit Kittiratpattana

π^- Beam

Low energy + Smaller system
→ Allow more cluster formations

- Hypernuclei formation
  - $\pi^- + N \rightarrow N^*$ (up to 4 GeV)
  - $N^* \rightarrow \Lambda K$ (or even $\Xi K K$)
  - Binding / Multifragmenting
    - $NN, \Lambda N, \Lambda NN, \ldots$

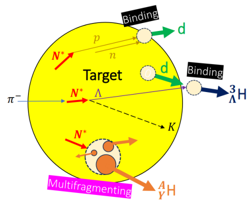


Figure 1: Schematic picture of hypernuclei formation

Our aim: Study the yield of cluster formations with coalescence and multifragmentation

Results

Total abundance for larger (hyper)nuclei

Signal extractions by HADES
- Light nuclei $A > 3 \rightarrow 10^{-4} - 1$ / event
- Hypernuclei $A > 3 \rightarrow 10^{-6} - 10^{-3}$ / event

HADES with $p_{\text{lab}} = 2.5$ GeV?
- Ξ-hypernuclei might be seen ($N^* \rightarrow \Xi + K + K$)
- Double-Λ? ($\Xi + N + N \rightarrow \Lambda + \Lambda + N$)

$\pi^- +$ C: $0 < b < 2.5$ fm, $\sigma_{tot}^{\pi^- + C} = 196.35$ mb
$\pi^- +$ W: $0 < b < 6.5$ fm, $\sigma_{tot}^{\pi^- + W} = 1327.32$ mb

Kittiratpattana, Apiwit, et al. *arXiv preprint arXiv:2305.09208* (2023).

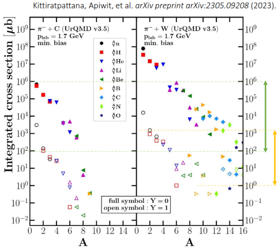
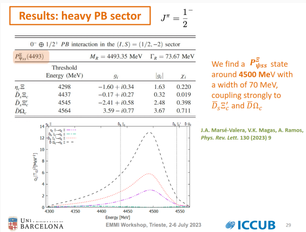
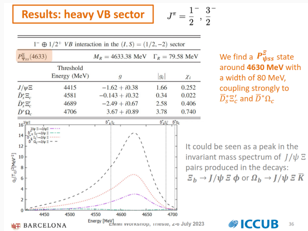
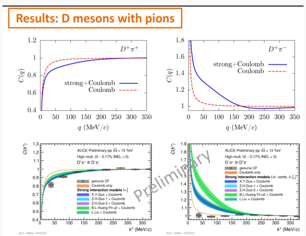


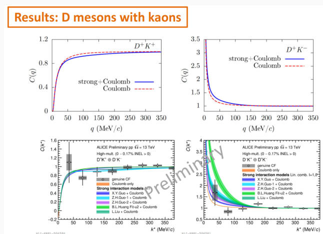
Figure 8: Integrated cross section

- Formation of light hypernuclei using the HADES π^- beam
- Using Two cluster-formation models: Coalescence and statistical multifragmentation
- Simulations show that it will be possible produce hypernuclei, including perhaps Ξ- and double-Λ hypernuclei





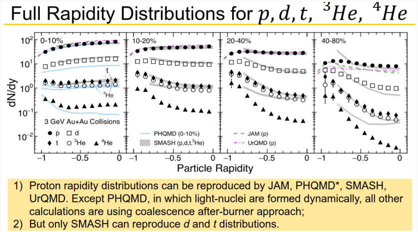


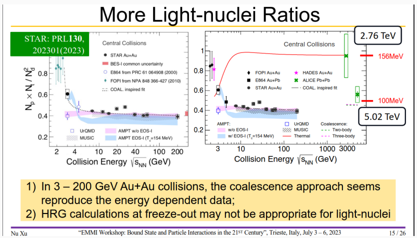


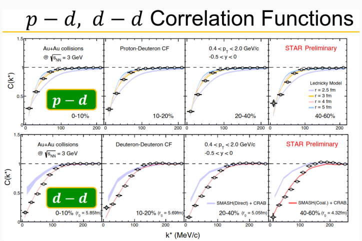
- Unitarized t-channel vector-meson exchange interaction
- Prediction of S=-2 pentaquarks at 4500 and 4630 MeV
- Calculated femtoscopic correlation functions of $D^{\pm}$-mesons and pions / kaons, show relatively good agreement, except for $D^{+}\pi^{-}$

Light Cluster Production and Baryon Correlation at High Density

Nu Xu







- Comparison of different hadronization models
- light nuclei are produced by coalescence and not thermalization
- production of light hypernuclei is consistent with light nuclei
- Correlations consistent with production

Thermal abundance of hyperons from a coupled-channel model
Pok Man Lo

- Scattering-matrix formulation of statistical mechanics
- Hadronization model which uses phase shifts – model independence