

# The Spectrum of Nuclear Unbound Isotopes $^9\text{He}$ and $^{10}\text{He}$

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JINR  
FLNR  
ACCULINNA

- $^9,^{10}\text{He}$  have been studied many times.
- There are contradictions in the interpretations of the obtained results

In this report:

- We discuss recent experimental results;
- Offer a theoretical explanation of observed picture.

## BEYOND THE DRIPLINE!

10C	11C	12C	13C	14C	15C	16C	17C	18C
9B	10B	11B	12B	13B	14B	15B	16B	17B
8Be	9Be	10Be	11Be	12Be	13Be	14Be	15Be	16Be
7Li	8Li	9Li	10Li	11Li	12Li	13Li		
6He	7He	8He	9He	10He				
5H	6H	7H						

— drip-line

What are waiting one there?

# $^{10}\text{He}$ Spectrum Studies I

Experiments on radioactive ion beams provide a way for  $^{10}\text{He}$  experimental studies

## Reactions with Halo-nuclei



A. A. Korshennikov, et al. PLB **326** (1994) 31 [ $^{11}\text{Li}$ ].



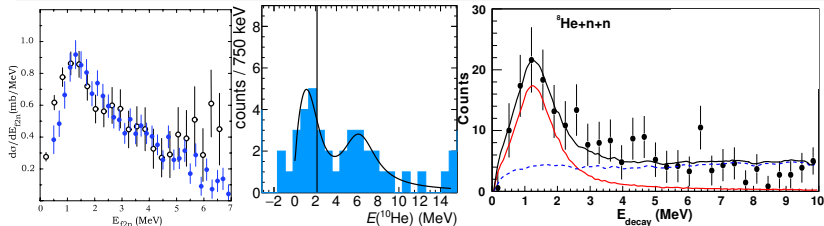
H. T. Johansson, et al. NPA **842** (2010) 15–32. [ $^{11}\text{Li}$ ]



A. Matta, et al. PRC **92** (2015) 041302. [ $^{11}\text{Li}(d, ^3\text{He})$ ]



Z. Kohley, et al. PRL **109** (2012) 232501. [ $^{14}\text{Be}$ ]



G.S. ( $J^\pi = 0^+$ ) located at 1.2 – 1.5 MeV.

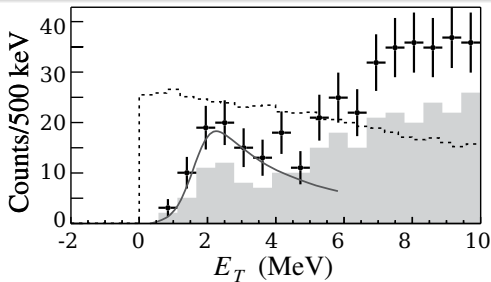
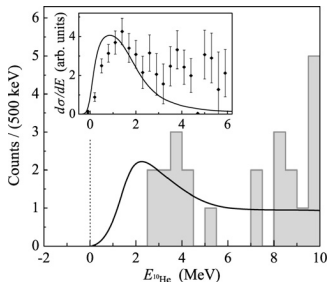
## $^8\text{He}(t,p)^{10}\text{He}$ -reaction



M. S. Golovkov, et al. PLB **672** (2009) 22.

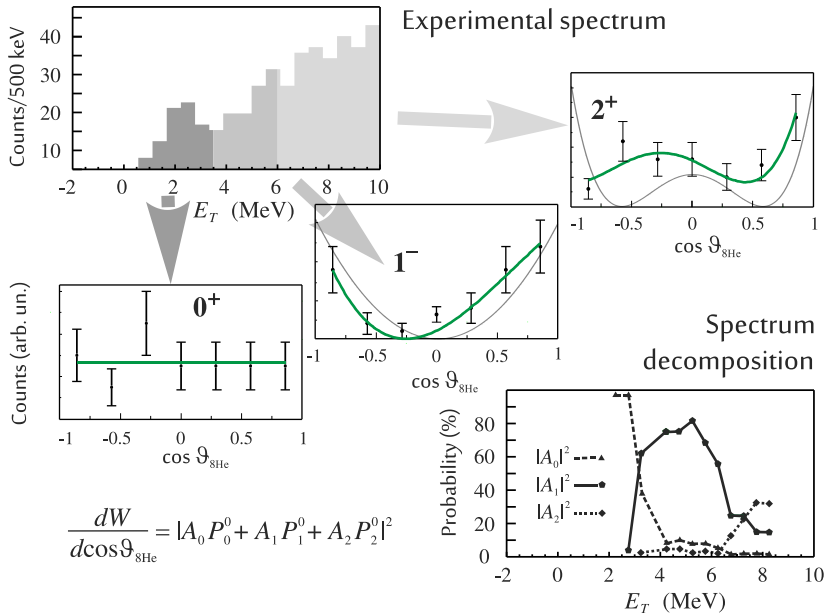


S. I. Sidorchuk et al. PRL **108** (2012) 202502.



- No state was observed at 1.2 – 1.5 MeV.
- G.S located at 2 MeV.

# $^{10}\text{He}$ Spectrum Studies III



# Reaction mechanism

Differences in the spectra behavior can be connected with influence of the reaction mechanism.

## Model with source

$$(\hat{H}_0 + \underbrace{\hat{V}_3}_{\text{FSI}} - E)\Psi = \underbrace{\Phi_q}_{\text{ISS}}$$

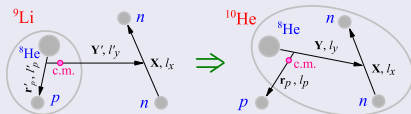
- Hyper-spherical harmonics method

## Model source

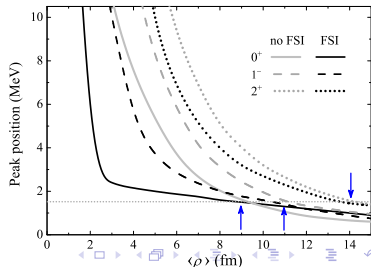
$$\Phi_{q,\gamma}^{JM}(X, Y) = \sum_{K,\gamma} N_{K,\gamma} \frac{f(\rho)}{\rho^{5/2}} \mathcal{J}_{K\gamma}^{JM}(\Omega_\rho),$$

$$f(\rho) = 21 \sqrt{\frac{7}{5}} \frac{\rho^{5/2}}{\rho_0^3} \exp\left[-\sqrt{\frac{21}{2}} (\rho/\rho_0)\right].$$

## Sudden Removal Approximation

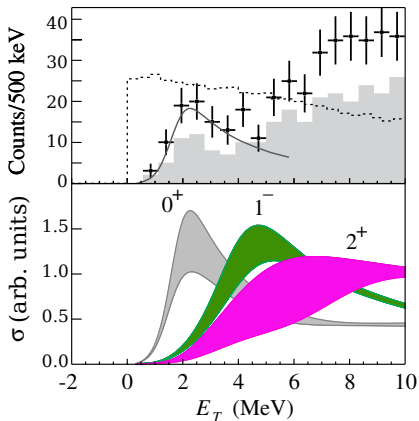


- Raynal-Revai transformation
- $\Phi_{\mathbf{q}} = \int d\mathbf{r}_p e^{i\mathbf{q}\mathbf{r}_p} \Psi_{11\text{Li}}$ .

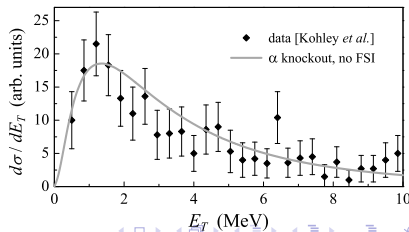
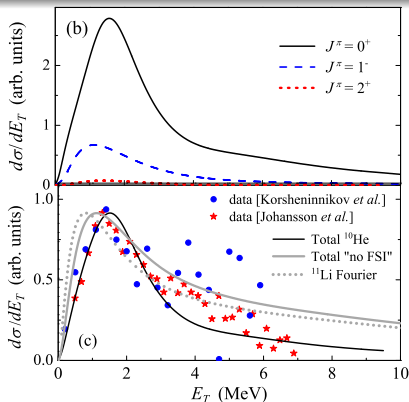


# Comparison with experimental data

- Differences in spectra can be explained by influence of ISS








- What about FSI?

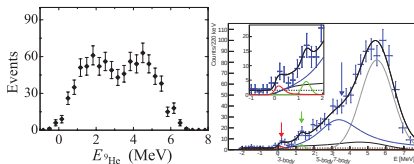
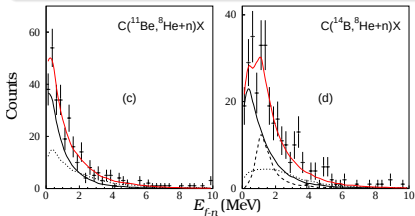


# $^9\text{He}$ Spectrum Studies

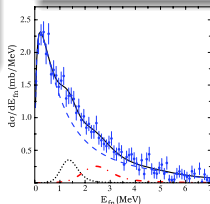
Properties of  $^8\text{He} + n$  interaction provide main contribution to FSI

## $^9\text{He}$ experimental studies

-  L. Chen, et al. PLB. **505** (2001) 21–26
-  H. T. Johansson, et al. NPA **847** (2010) 66.
-  Falou H. A., Leprince A., Orr N. JoP **312** (2011) 092012
-  M. S. Golovkov, et al. PRC **72** (2005) 064612
-  T. Al Kalanee, et al. PRC **88** (2013) 034301








$J^\pi$  assignment is possible in the  $(d, p)$ -reaction.



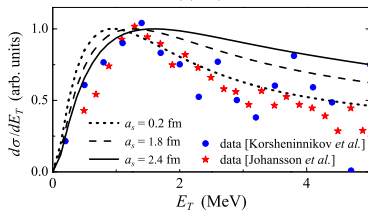
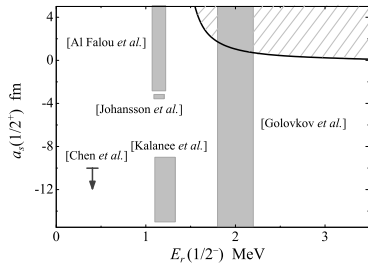
All experiments have rather poor statistic for analysis of  $^9\text{He}$  broad states.

# Restrictions on ${}^9\text{He}$ properties

## ${}^9\text{He}$ experimental studies

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- Calculation reproduce low-energy spectrum behavior only for restricted range of parameters.
- The results of the experiment conducted in Dubna are in good agreement with observed picture.





- We propose a theoretical explanation of the observed differences between  $^{10}\text{He}$  spectra populated in different reactions.
- From the three-body spectrum studies one can obtain restrictions for the interactions in the binary subsystems.
- The effects discussed in the talk can be observed in other system beyond the neutron drip-line.
- The unbound nuclear systems should be studied in different reactions.