

# Search for eta-mesic helium via deuteron-deuteron reactions with the WASA-at-COSY facility

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**INTERNATIONAL PHD PROJECT IN APPLIED NUCLEAR PHYSICS AND INNOVATIVE TECHNOLOGIES**

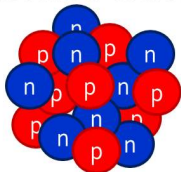
This project is supported by the Foundation for Polish Science-MPD program co-financed by the European Union within the European Regional Development Fund

# Outline

- 1 Introduction
- 2 Search for  $\eta$ -mesic nuclei with WASA-at-COSY
- 3 Experimental status
- 4 Summary and perspectives

# $\eta$ -mesic bound state

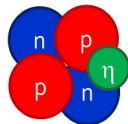
## Atomic nucleus



**STRONG  
INTERACTION**

## $\eta$ -mesic nucleus

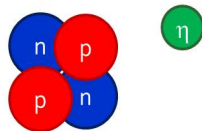
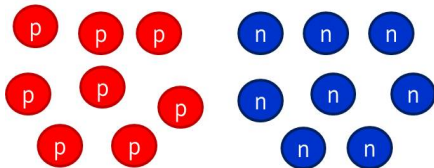
${}^4\text{He}-\eta$



$$m = Z \cdot m_p + N \cdot m_n - B_s$$

$$B_s = \Delta mc^2$$

$$m_{bs} = m_{{}^4\text{He}} + m_\eta - B_s$$



# $\eta$ -mesic bound state

Conditions for the existence  
of eta-mesic nuclei



$$\operatorname{Re} a_{\eta\text{-nucleus}} < 0$$

$$|\operatorname{Re} a_{\eta\text{-nucleus}}| > |\operatorname{Im} a_{\eta\text{-nucleus}}|$$

**Attractive** interaction between  $\eta$  and N

R. Bhalerao, L. C. Liu, Phys. Lett. B54, 685 (1985)



**possible existence of  $\eta$ -mesic bound state for  $A > 12$**

Q. Haider, L. C. Liu, Phys. Lett. B172, 257 (1986)

# $\eta$ -mesic bound state

Recent theoretical investigations of  
hadronic- and photoproduction of  $\eta$  meson

$$0.27 \text{ fm} \leq \text{Re} a_{\eta N} \leq 1.05 \text{ fm}$$

$$0.19 \text{ fm} \leq \text{Im} a_{\eta N} \leq 0.39 \text{ fm}$$

Q. Haider, L. C. Liu, Phys. Lett. C66, 045208 (2002).

$$\Gamma \in (7,40) \text{ MeV}$$

$$B_s \in (5,15) \text{ MeV}$$



# Production of ${}^4\text{He}-\eta$ in dd collision

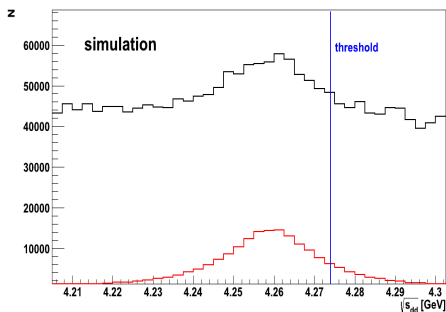
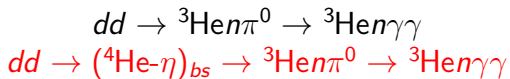
$$dd \rightarrow ({}^4\text{He}-\eta)_{bs} \rightarrow {}^3\text{He} p \pi^-$$

$$dd \rightarrow ({}^4\text{He}-\eta)_{bs} \rightarrow {}^3\text{He} n \pi^0 \rightarrow {}^3\text{He} n \gamma \gamma$$

$$dd \rightarrow ({}^4\text{He}-\eta)_{bs} \rightarrow d p p \pi^-$$

$$dd \rightarrow ({}^4\text{He}-\eta)_{bs} \rightarrow T p \pi^0 \rightarrow T p \gamma \gamma$$

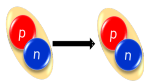
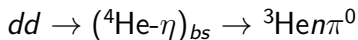
# Experimental method



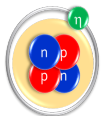
## Excitation function

$({}^4\text{He}-\eta)_{bs}$  existence manifested by resonant-like structure below  $\eta$  production threshold

# Kinematical mechanism of the reaction



DEUTERON FUSION



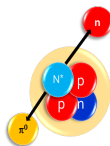
CREATION OF  $\eta$ -MESIC NUCLEUS



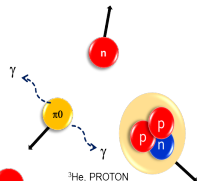
ABSORPTION OF  $\eta$  MESON BY ONE OF NUCLEON INSIDE THE HELIUM



NUCLEON EXCITATION INSIDE THE NUCLEUS –  $N^*$  RESONANCE FORMATION



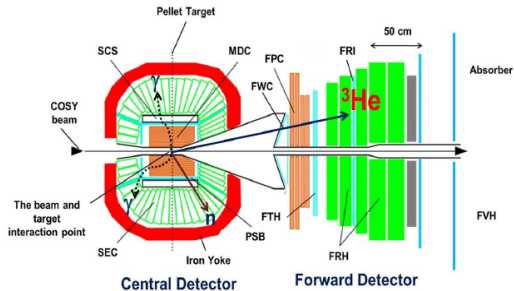
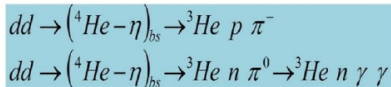
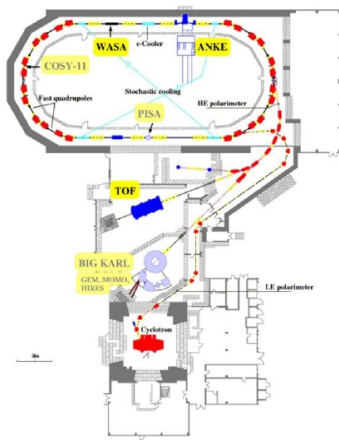
RESONANCE DECAY INTO PION AND PROTON INSIDE NUCLEUS



${}^3\text{He}$ , PROTON AND MESON  $\pi^0$  EMISSION



# Search for $\eta$ -mesic nuclei with WASA-at-COSY



# Experiment-May 2008

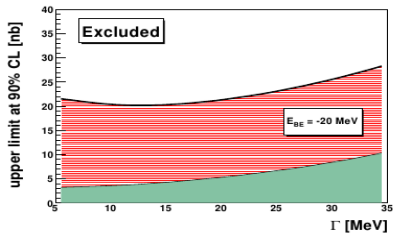
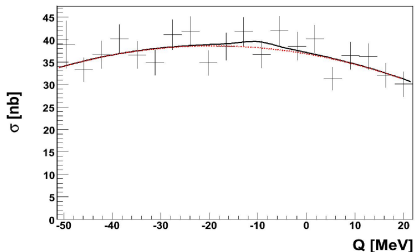
**Channel:**  $dd \rightarrow (^4\text{He}\eta)_{bs} \rightarrow ^3\text{He}p\pi^-$

**Measurement:** performed with the beam momentum ramped from  $2.185\text{GeV}/c$  to  $2.400\text{GeV}/c$ , corresponding to the range of excess energy  $Q \in (-51, 22)\text{MeV}$

**Time:**  $T=16.5\text{h}$

**Luminosity:**  $L=3 \cdot 10^{30} \text{cm}^{-2} \text{s}^{-1}$

**Acceptance:**  $A=53\%$



W. Krzemien et al. [arXiv:1301.0843](https://arxiv.org/abs/1301.0843)

# Experiment-Nov/Dec 2010

**Beamtime:** Nov 26 - Dec 13, 2010

**Channels:**  $dd \rightarrow (^4\text{He}-\eta)_{bs} \rightarrow ^3\text{He}p\pi^-$   
 $dd \rightarrow (^4\text{He}-\eta)_{bs} \rightarrow ^3\text{He}n\pi^0 \rightarrow ^3\text{He}n\gamma\gamma$

**Measurement:** performed with the beam momentum ramped from **2.127 GeV/c to 2.422 GeV/c**, corresponding to the range of excess energy  **$Q \in (-70, 30) \text{ MeV}$**

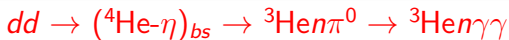
**Time:** T=154h

**Acceptance:** A=53%

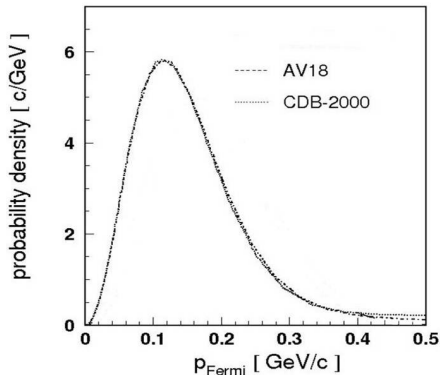
**Luminosity:**  $L=8.2 \cdot 10^{30} \text{ cm}^{-2} \text{ s}^{-1}$



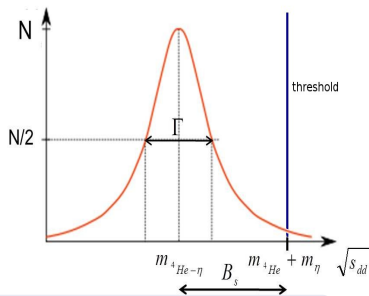
More than **40 times higher** statistics were collected than in experiment carried out in 2008.



Spectator Model



Breit-Wigner distribution

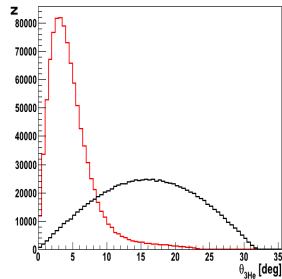
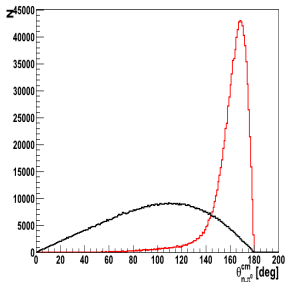
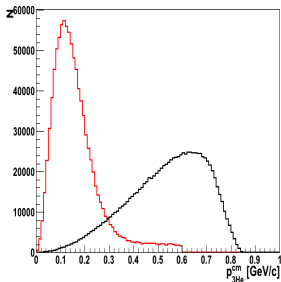
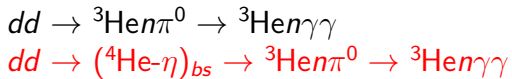


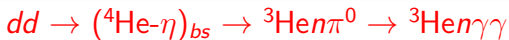
$$N(\sqrt{S_{dd}}) = \frac{1}{2\pi} \frac{\Gamma}{(\sqrt{S_{dd}} - m_{bs})^2 + \Gamma^2/4}$$

$$m_{{}^4\text{He}-\eta} = m_{{}^4\text{He}} + m_\eta - B_s$$

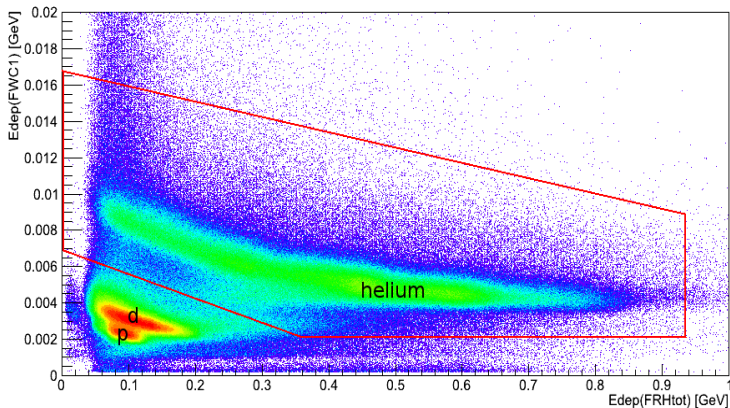
$$\Gamma \in (5, 40) \text{ MeV}$$

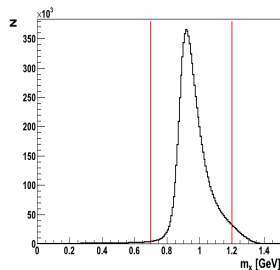
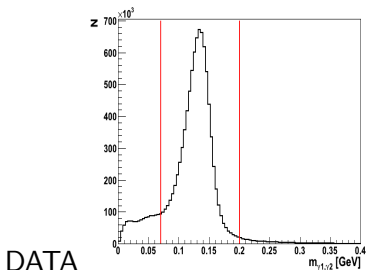
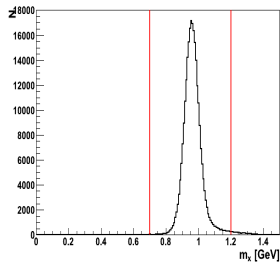
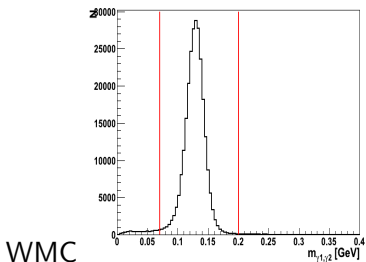
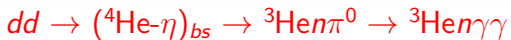
$$B_s \in (5, 20) \text{ MeV}$$



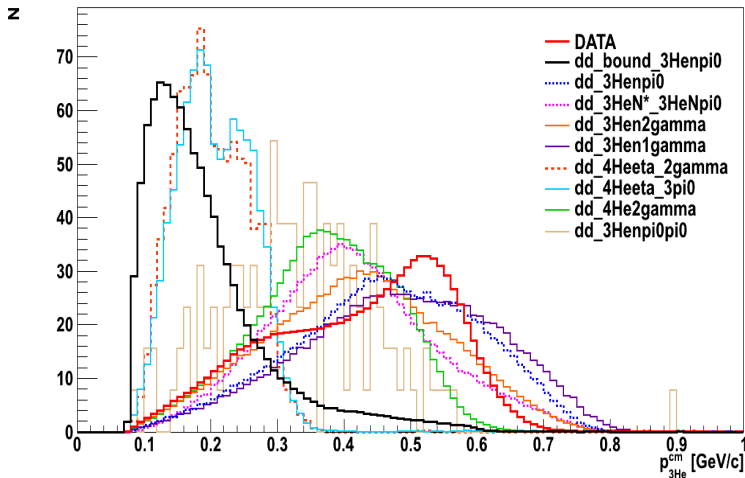


1 charged in FD,  $\geq 2$  neutral tracks in CD, no charged in CD





## Background studies





# Plans for future

- 1 Determination of excitation functions for  $dd \rightarrow {}^3\text{He}n\pi^0$  and  $dd \rightarrow {}^3\text{He}p\pi^-$  reactions
- 2 Luminosity determination in order to normalize the selected events ( $dd \rightarrow {}^3\text{He}n$  reaction)
- 3 Determination of the upper limit of the total cross section for the production of the bound state

# Summary and perspectives

Chance for the discovery of the  $({}^4\text{He}-\eta)_{bs}$  with the WASA-at-COSY facility (study of the excitation function)



- Determination of the bound state **width** and **binding energy** of  $({}^4\text{He}-\eta)_{bs}$
- Investigation of interaction of the  $\eta$  meson and the nucleons inside a nuclear matter
- Information about resonances in nuclear matter ( $N^*(1535)$ )
- Information about  $\eta$  meson structure (wave function)

If no peak observed  $\Rightarrow$  determination of **the upper limit of the total cross section** with accuracy of **few nb**.

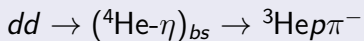
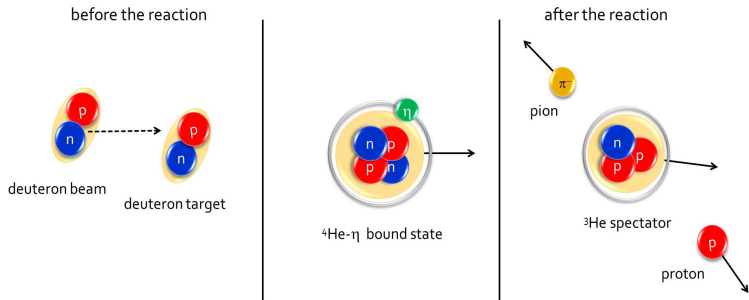
# Thank you for attention



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# Spectator model



$$|\mathbb{P}_{sp}|^2 = m_{sp}^2$$