Search for the He-η bound state with the WASA-at-COSY facility

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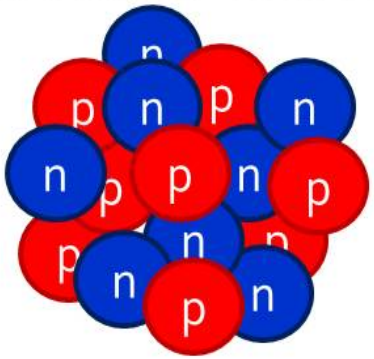
Outline

η-mesic bound state

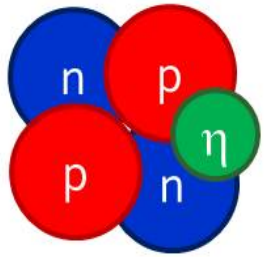
Atomic nucleus



STRONG INTERACTION

η-mesic nucleus

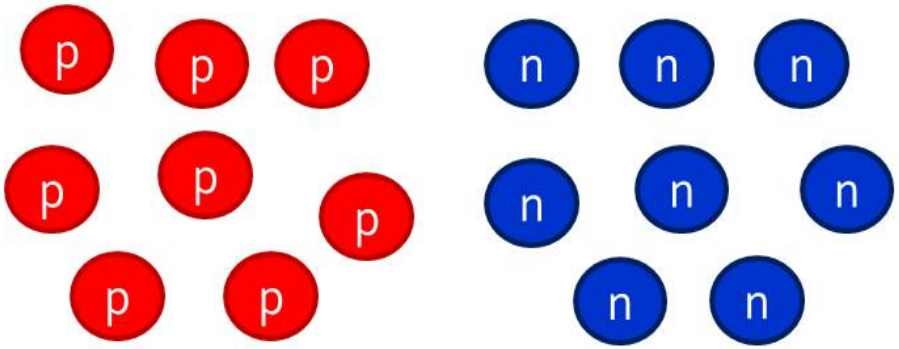
^4He-η

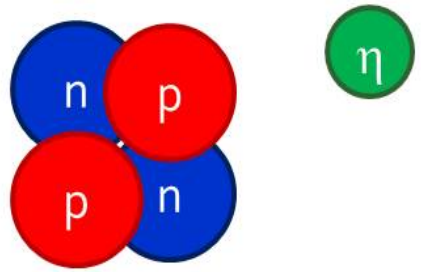


$$m = Z \cdot m_p + N \cdot m_n - B_s$$

$$B_s = \Delta m c^2$$

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





η-mesic bound state

Conditions for the existence of eta-mesic nuclei

$$\mathrm{Re}\, a_{\eta-nucleus} < 0$$

$$\left|\mathrm{Re}\, a_{\eta-nucleus}\right| > \left|\mathrm{Im}\, a_{\eta-nucleus}\right|$$

Attractive interaction between η and N

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

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possible existence of η-mesic bound state for A>12

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

η-mesic bound state

Recent theoretical investigations of hadronic- and photoproduction of η meson

$$0.27\,fm \le \mathrm{Re}\,a_{\eta N} \le 1.05\,fm$$
$$0.19\,fm \le \mathrm{Im}\,a_{\eta N} \le 0.39\,fm$$

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

$$\Gamma \in (7,40)MeV$$
$$B_s \in (5,15)MeV$$

$(^4\mathrm{He}\text{-}\eta)_{bs}$ $(\mathrm{T}\text{-}\eta)_{bs}$
$(^3\mathrm{He}\text{-}\eta)_{bs}$ $(\mathrm{d}\text{-}\eta)_{bs}$

$a_{\eta-N} = (0.51+0.21i)\,fm$ ISOBAR MODEL

$B_{\eta-^4He} = 6.30\,MeV$
$\Gamma_{\eta-^4He} = 11.47\,MeV$

No ^{3}He-eta bound state exists

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

$a_{\eta-N} = (0.50+0.33i)\,fm$ SPES-2 $pd \to {}^3He\eta$

$a_{\eta-^4He} = (-2.00+0.97i)\,fm$ $a_{\eta-^3He} = (-2.31+2.57i)\,fm$

C. Wilkin, Phys. Rev. C47, R938 (1993).

Production of ^{4}He-η in dd collision

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

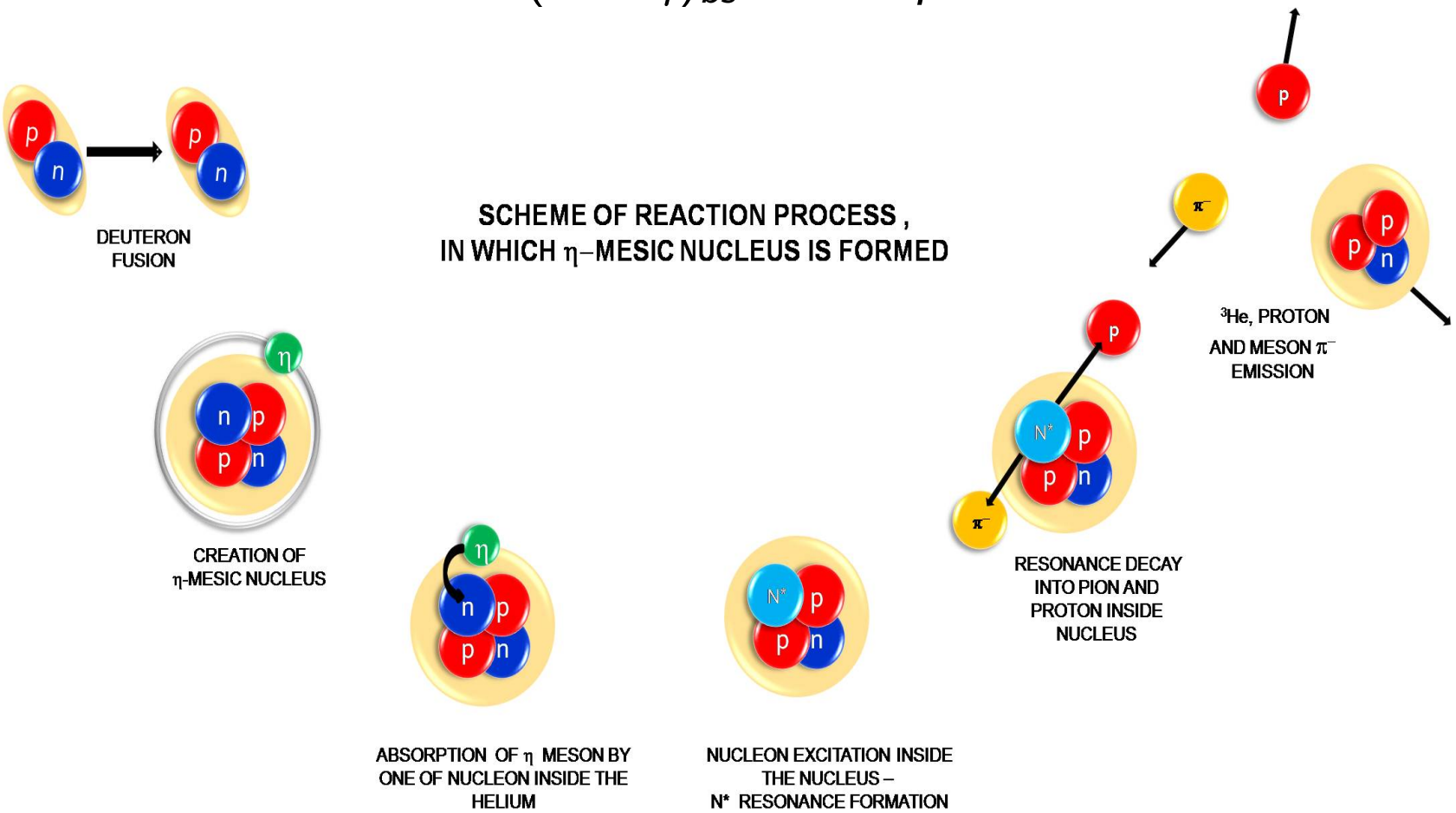
$$dd \rightarrow \left({}^4He-\eta\right)_{bs} \rightarrow {}^3He\ n\ \pi^0 \rightarrow {}^3He\ n\ \gamma\ \gamma$$

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

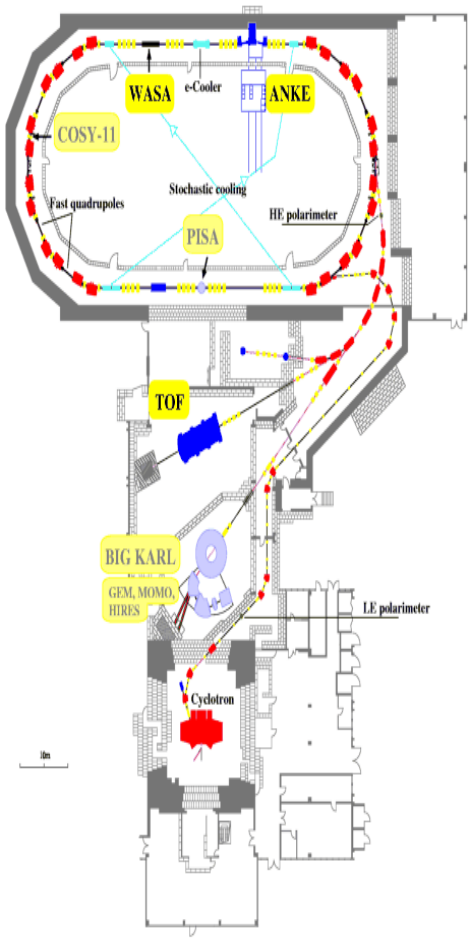
$$dd \rightarrow \left({}^4He-\eta\right)_{bs} \rightarrow T\ p\ \pi^0 \rightarrow T\ p\ \gamma\ \gamma$$

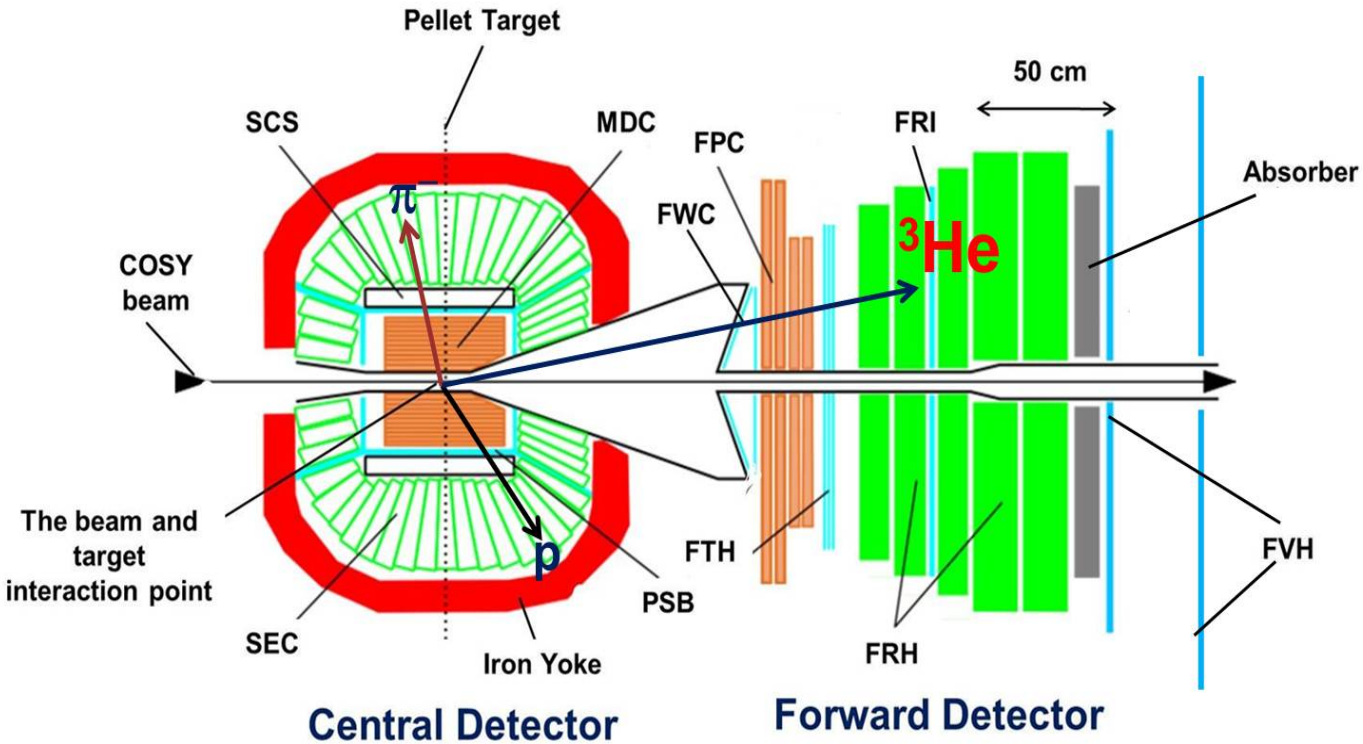
Kinematical mechanism of the reaction

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



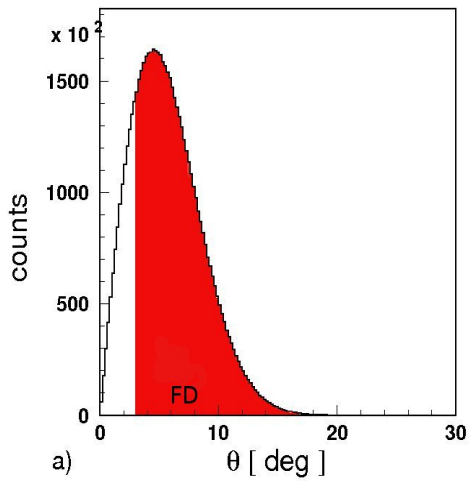
Search for η-mesic nuclei with WASA-at-COSY



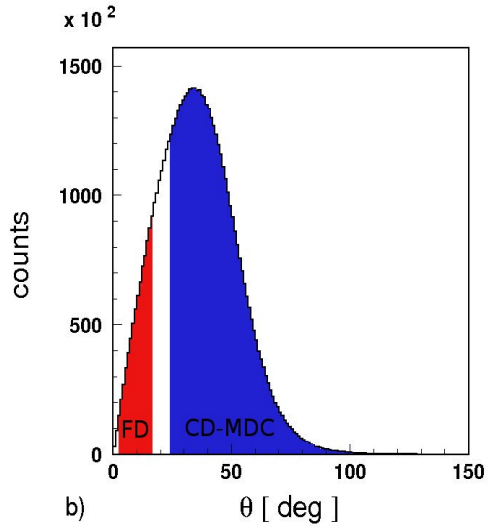


Angular distributions of outgoing particles

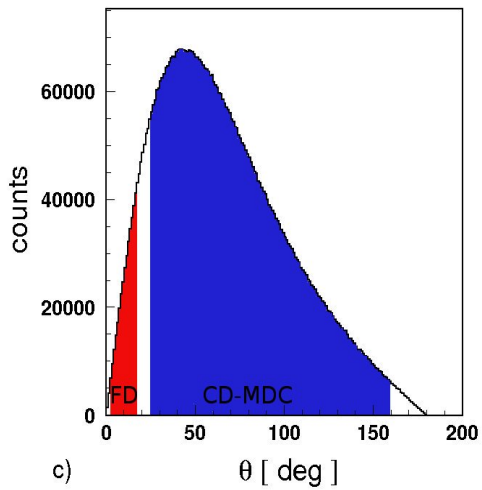
$$dd \rightarrow ({}^4\text{He-}\eta)_{bs} \rightarrow {}^3\text{He}p\pi^-$$



^{3}He



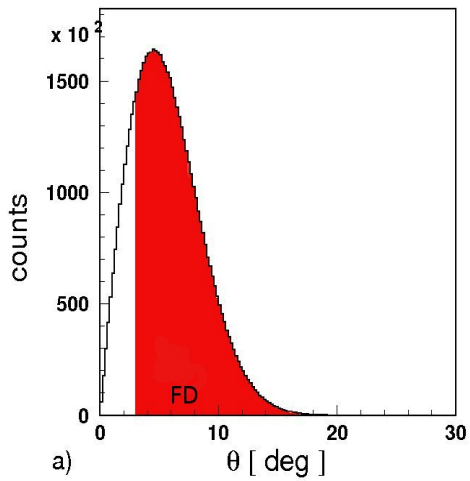
proton

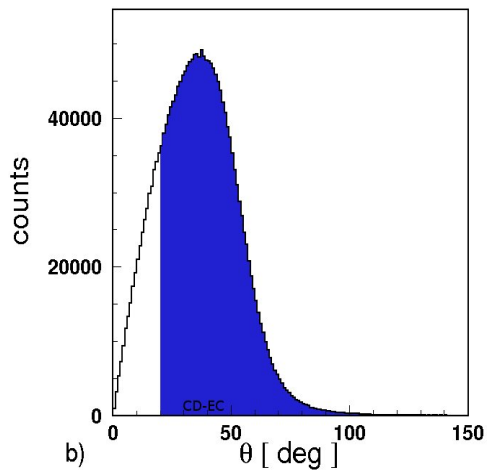


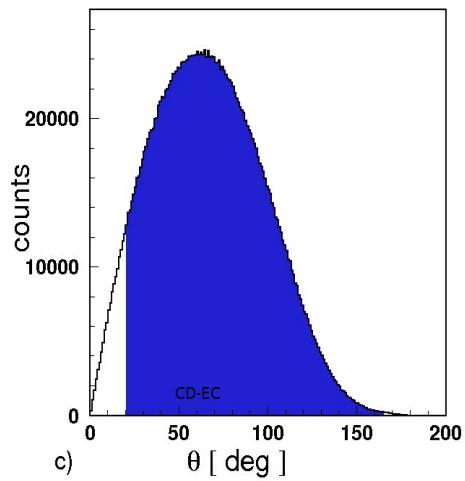
pion

Angular distributions of outgoing particles

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







^{3}He neutron gamma

Geometrical acceptance

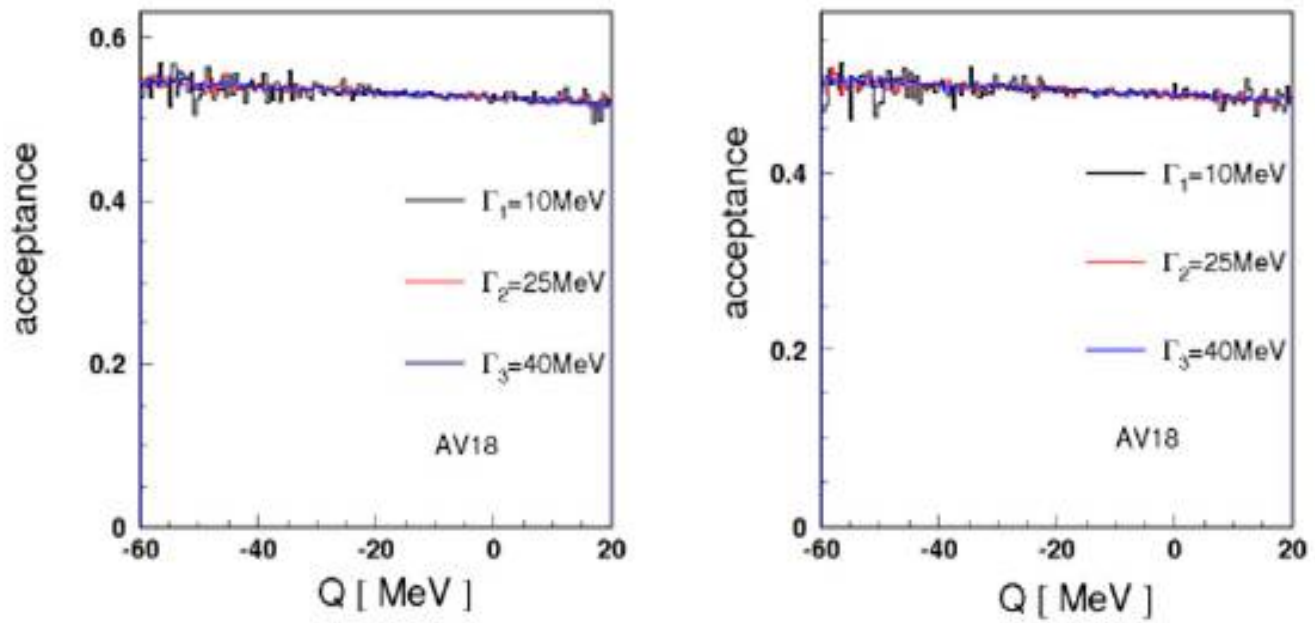


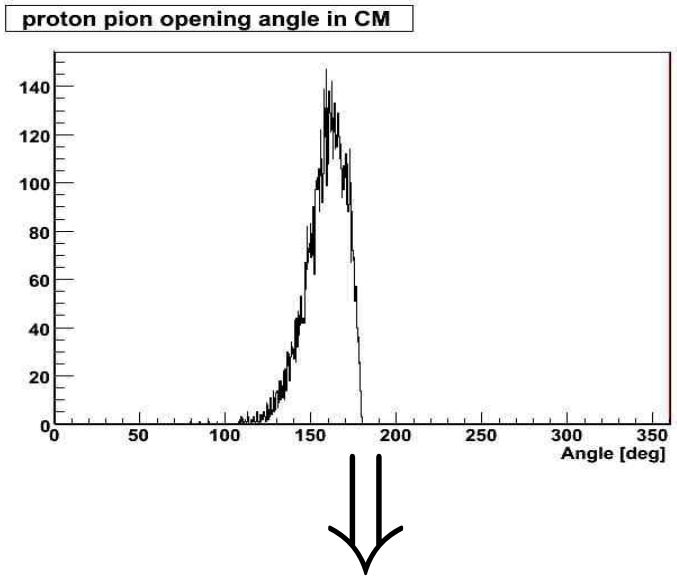
Figure 2.1: Geometrical acceptances of the WASA-at-COSY detector for the $dd \to (^4\text{He-}\eta)_{bs} \to {}^3\text{He}p\pi^-$ (left) and $dd \to (^4\text{He-}\eta)_{bs} \to {}^3\text{He}n\pi^0 \to {}^3\text{He}n\gamma\gamma$ reaction (right). Acceptance is calculated for three different bound state width values and AV18 potencial model describing nucleon momentum distribution inside ^{4}He.

Simulation-assumptions

- Resonant structure of the eta-mesic bound state given by Breit-Wigner distribution (with assumed width and binding energy)
- Nucleon momenta in atomic nuclei described by Fermi distributions
- Spectator model

Expected results of the measurement

Angle between p and π^- in the CM frame $\Theta_{CM_{N*}} = 180^0$



Excitation function

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

Experiment-May 2008

Exp. No. 186.1: Search for the η-He bound state with WASA-at-COSY

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

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

Time: T=16.5h
Acceptance: A=53%
Luminosity: L=$3 \cdot 10^{30} cm^{-2} s^{-1}$

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Upper limit of the total cross section: σ=20nb

Experiment-Nov/Dec 2010

Exp. No. 186.2: Search for the η-He bound state with WASA-at-COSY

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 **2.127GeV/c to 2.422GeV/c**, corresponding to the range of excess energy **Q$\in$(-70,30)MeV**

Experiment-Nov/Dec 2010

Time: T=154h
Acceptance: A=53%
Luminosity: L=$8.2 \cdot 10^{30} cm^{-2} s^{-1}$

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Taking into account the fact that there were two reactions measured, in total more than **40 times higher** statistics were collected than in experiment carried out in 2008.

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)

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

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

Thank you for attention