An analysis of the 12C(p,d) reaction at eta'(958) meson production region by microscopic transport model (JAM)

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1, Introduction

- The experiments of the $^{12}\mathrm{C}(p,d)$ reaction at GSI and FAIR for the formation of η'(958) mesic nucleus are considered.
- Investigation of η'(958) meson bound state in nuclei by the missing mass spectroscopy is considered.
- To improve S/N ratio by reducing the background, semi-exclusive measurements are considered at FAIR, where protons /charged pions are measured in coincidence with the deuteron.

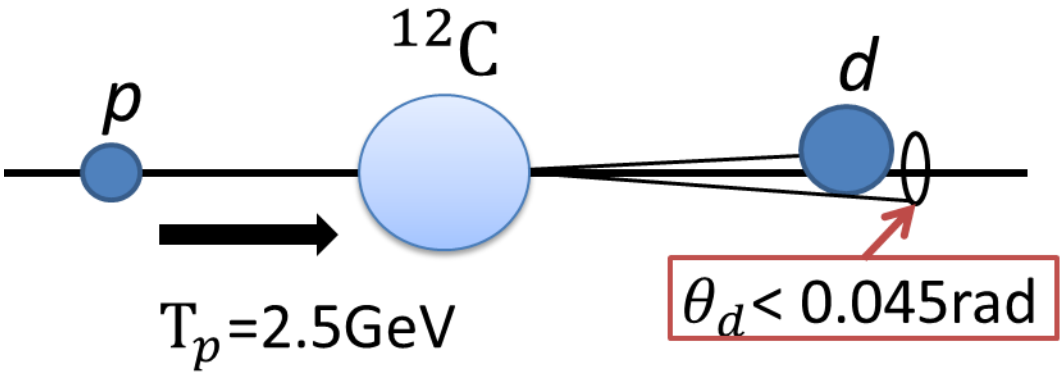
<This study>

- Numerical (theoretical) simulation of **Physical Processes**.
- Quantitative discussions for the reduction of the background.
- Numerical simulation by the microscopic transport model JAM.

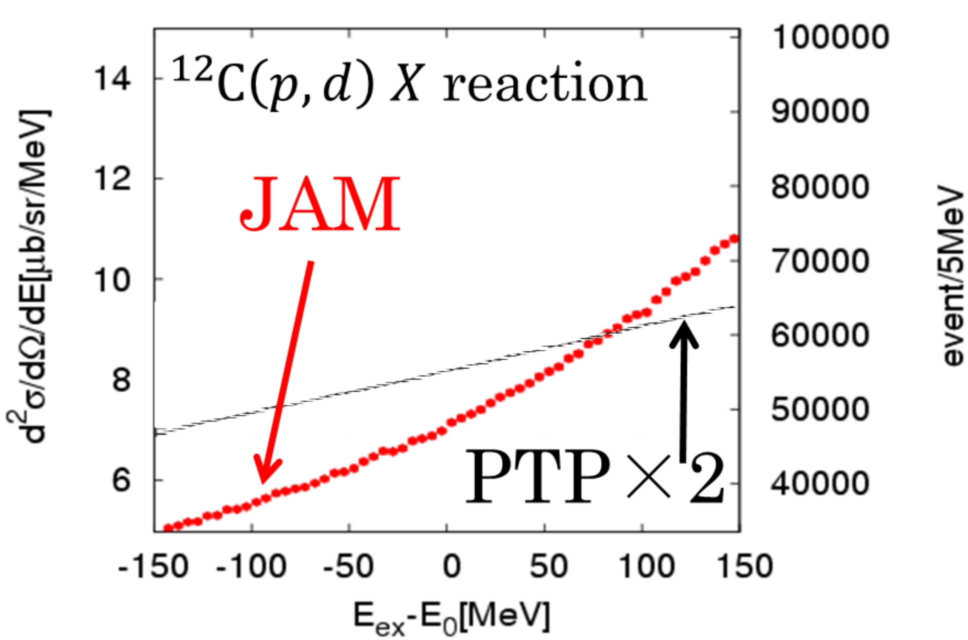
JAM was developed by
Y. Nara, N. Otuka, A. Ohnishi, K. Niita, S. Chiba,
Phys. Rev. C61, 024901 (2000).

$^{12}\mathrm{C}(p,d)$ Inclusive reaction

<Simulation conditions for inclusive $^{12}\mathrm{C}(p,d)$ reaction>



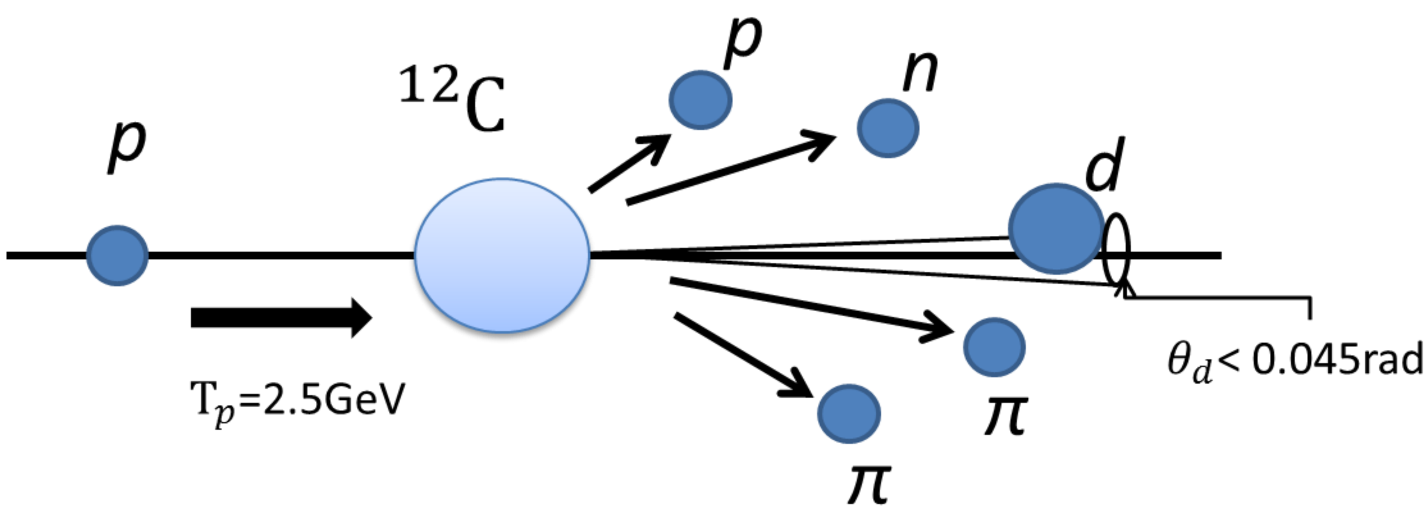
- T_p =2.5GeV
- forward deuteron: θ_d< 0.045rad
- number of incident proton : 6.0×10^{10}



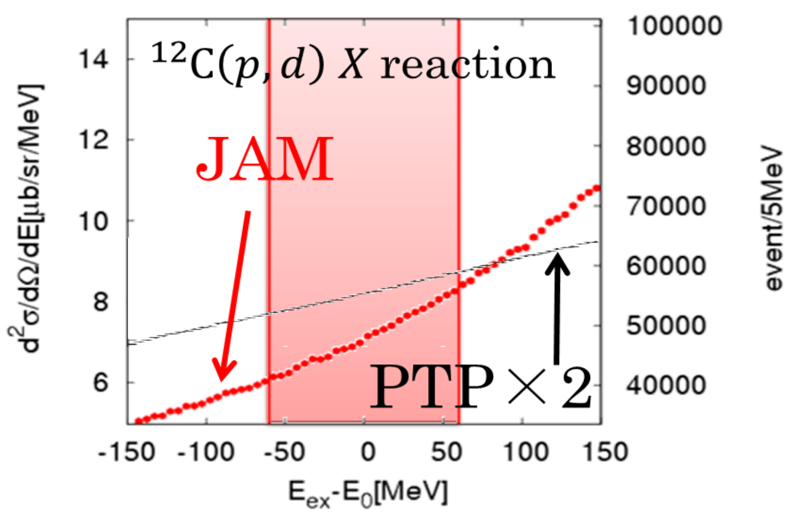
Simulated results by JAM and another evaluation by Itahashi et al. are consistent within the factor of 2.

K. Itahashi et al.,
Progress of Theoretical Physics
Vol. 128, No. 3, 601（2012）

<u>Background events:</u> (mainly due to multi π production)



Considered range of the missing mass : η' threshold ± 60MeV.



By JAM, the distributions of emitted particles from No-η'-Processes can be investigated.

⇒ **<u>Background</u>**

<u>η' - Processes :</u> Emitted particles from η' - Processes ⇒**<u>Signal</u>**

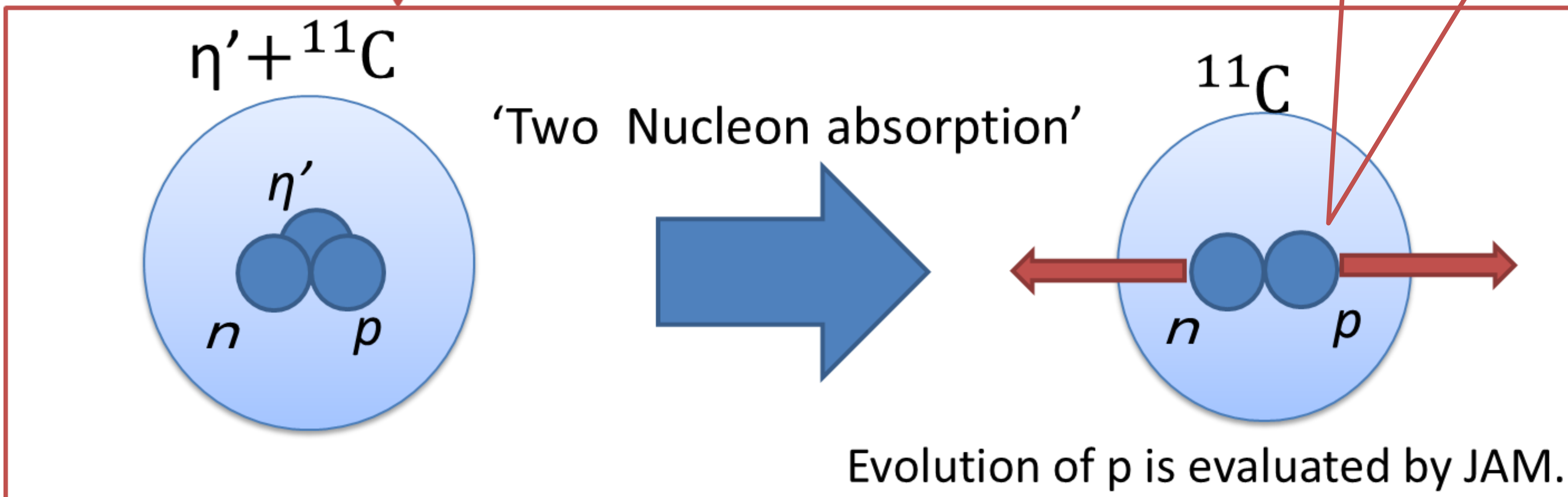
Here, we consider two-Nucleon absorption of η'

$$p + {}^{12}\mathrm{C} \rightarrow \mathrm{d} + \underline{(\eta' \;\; {}^{11}\mathrm{C})}$$

Proton has

$$\mathrm{T}_p \sim \frac{m_{\eta'}}{2}$$

$$|\overrightarrow{P_p}| \sim 1\mathrm{GeV/c}$$



Simulation was started by putting 1.0×10^6 protons in nucleus.

Spatial distribution $\propto$ $\rho(\mathrm{r})^2$: 2 nucleon absorption

Momentum distribution $\propto$ $\exp\left[\frac{-(\vec{P}-\overrightarrow{P_0})^2}{2(\Delta\vec{P})^2}\right]$: Fermi Motion

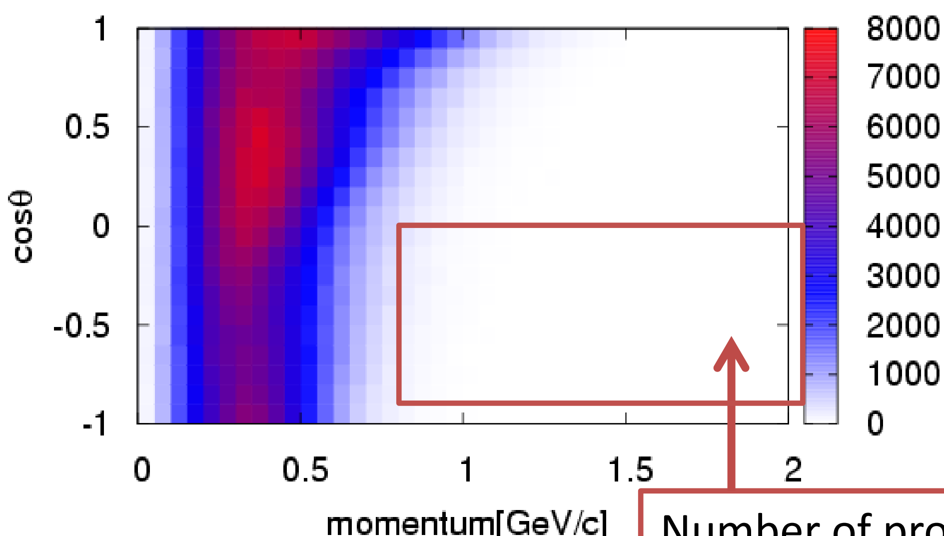
Simulation results: Comparison of Signal with Background

- Signal ⟶ Emitted particles from η' absorption.
- Background ⟶ Emitted particles from No-η'-processes.

To improve S/N ratio ⇒ **Focus on proton of $^{12}\mathrm{C}(p,d)p\ X$**

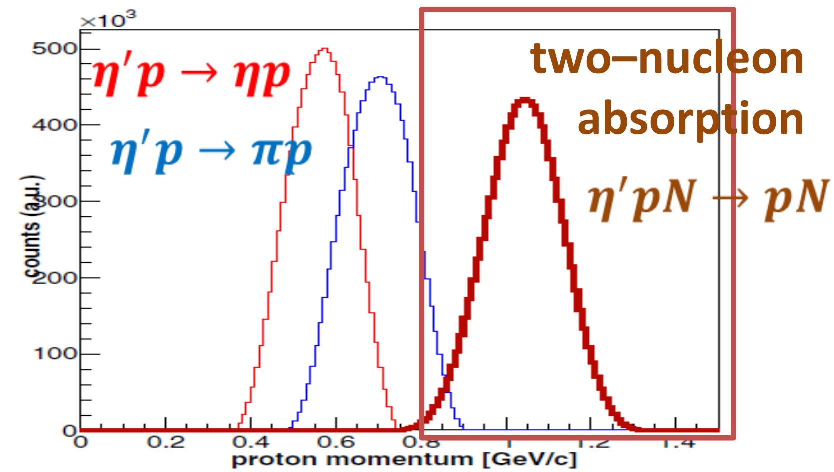
Background

(calculation by JAM)



Signal

Expected momentum distribution of proton just after η' absorption in nucleus

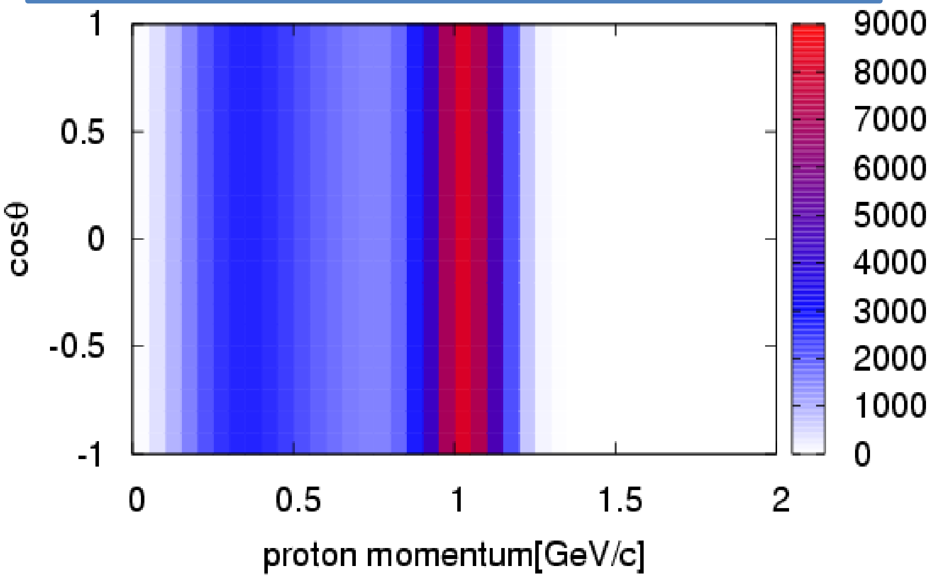


Number of protons with large momentum at backward directions : small!

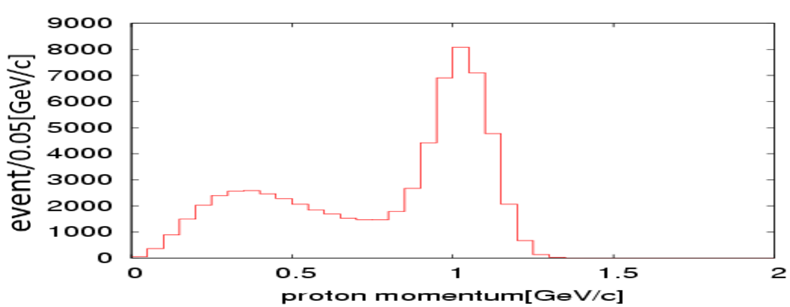
⇒ The S/N ratio could be improved by using the protons from two-nucleon absorption of η'! (proton with large momentum at backward directions seems important.)

<u>Simulation results</u>: Distribution of emitted protons from two–nucleon absorptions of η’ by JAM (<u>**Signal**</u>)

The momentum–angular distribution of emitted protons

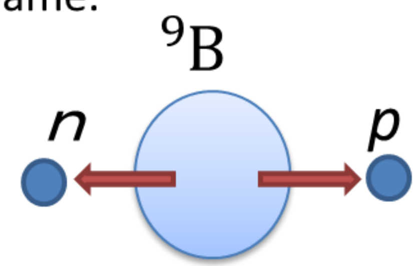


Event number as the function of proton momentum.

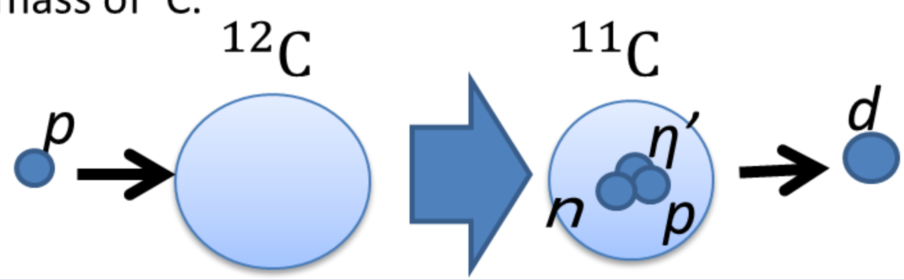


Distribution of emitted protons
⇒No angular dependence.

1, Proton is emitted isotropically in the η’-nucleus rest frame.



2, The rest frame of the η’-nucleus is nearly same as the laboratory system due to heavy mass of C.



3.Discussion : Comparison of Signal with Background (obtained by independent simulations)

Event number and (*p,d*) cross section

<Background>

$$\frac{d\sigma}{d\Omega} \sim 760[\mu b/sr]$$

for the energy range

$$E_{ex} - E_0 = \pm 60[MeV]$$

<Signal>

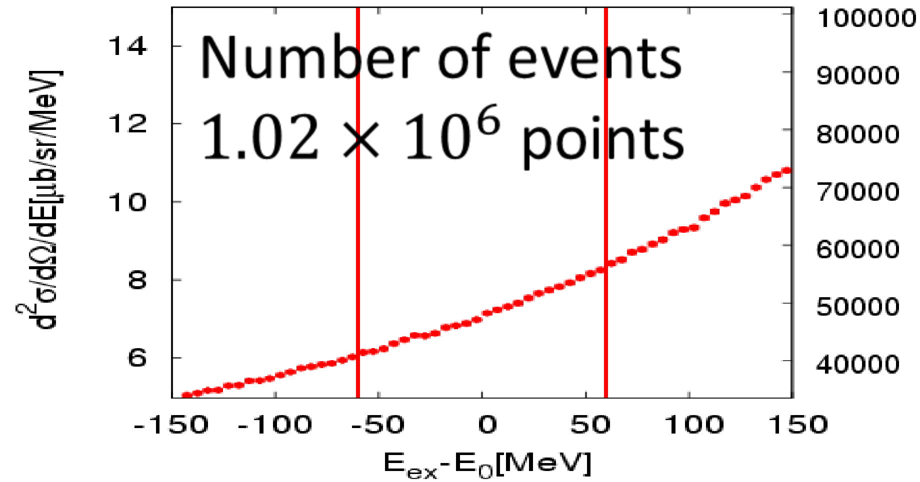
$$\frac{d\sigma}{d\Omega} \sim 1.1[\mu b/sr]$$

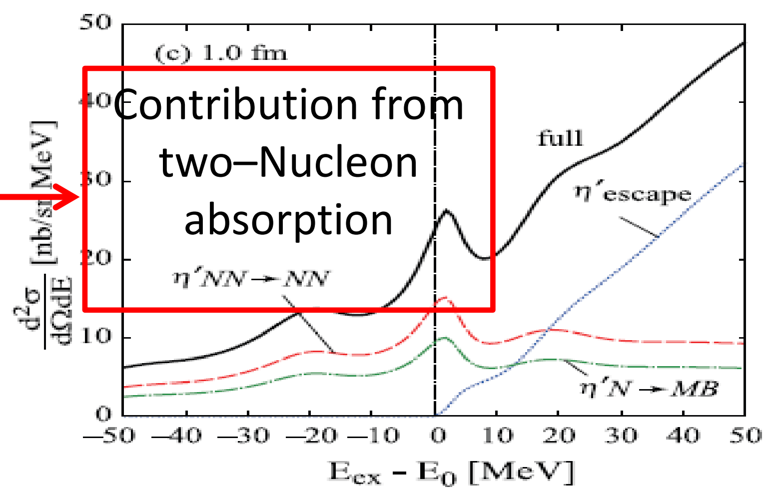
for the energy range

$$E_{ex} - E_0 = \pm 60[MeV]$$

Thus, the S/N ratio of $^{12}\mathrm{C}(p,d)\,X$ reaction is

$$\textbf{S/N ratio} \sim \frac{1.1}{760} \sim 1.4 \times 10^{-3}$$

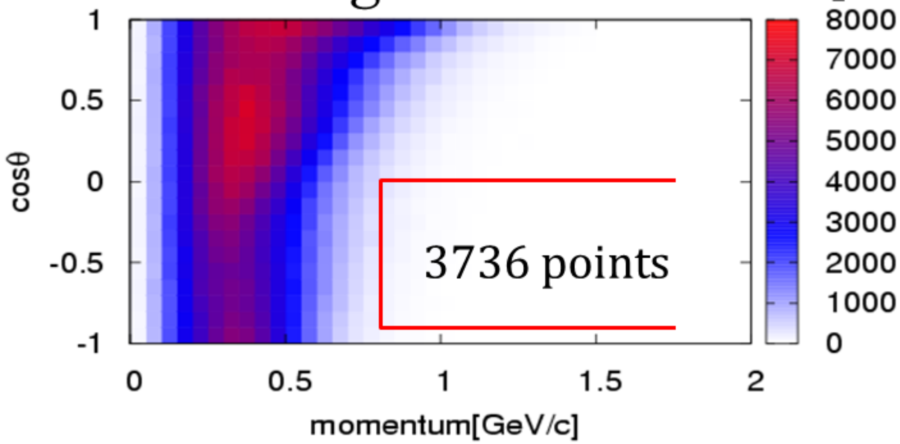




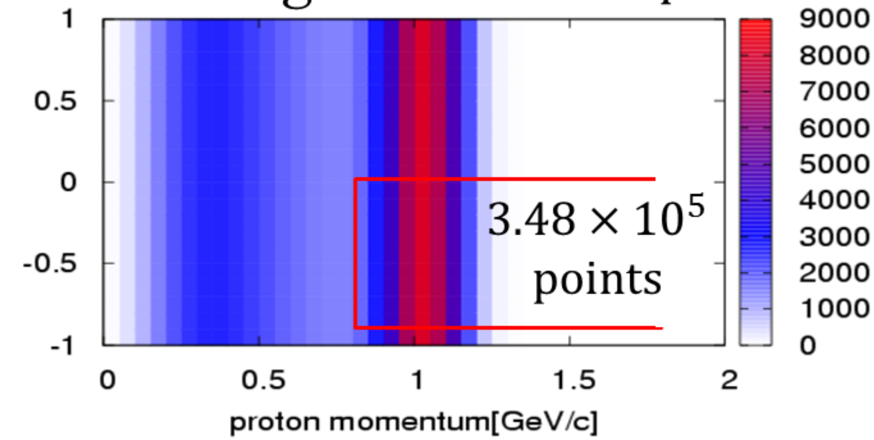
H. Nagahiro et al.,
Phys. Rev. C87, 045201(2013)

3.Discussion : Comparison of Signal with Background (obtained by independent simulations)

Background (1.06×10^6 points)



Signal (1.0×10^6 points)



	Inclusive(*p*,*d*) $\frac{d\sigma}{d\Omega_d}$ ※1		proton cut $\frac{d\sigma}{d\Omega_d}$ ※2
Background	760 [μb/sr]	$\times \frac{3736}{1.06 \times 10^6} \rightarrow$	2.68 [μb/sr]
Signal	1.1 [μb/sr]	$\times \frac{3.48 \times 10^5}{1.0 \times 10^6} \rightarrow$	0.38 [μb/sr]

→We calculate the S/N ratio by taking the ratio of Background and Signal cross sections.

※1 Calculated by integrating the cross section within the range of ±60MeV from η' production threshold.

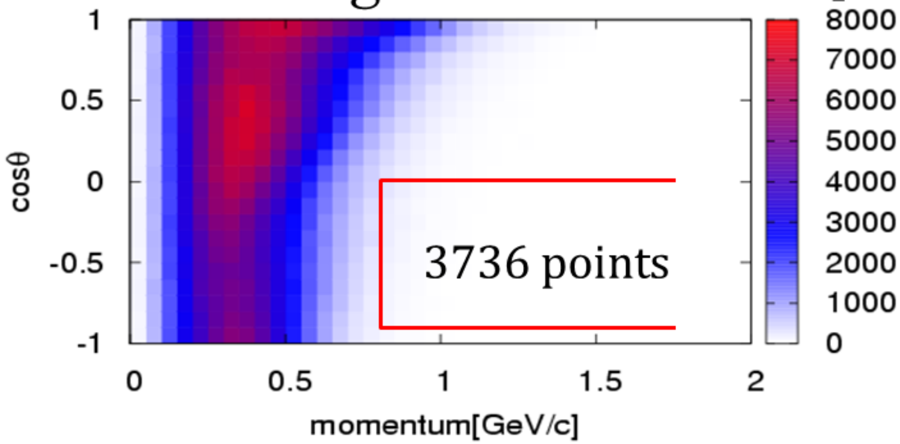
$$\int dE_d \times \frac{d^2\sigma}{d\Omega_d dE_d}$$

※2 Add restrictions, $|\overrightarrow{P_p}|$> 0.8GeV/c and $-0.9 < \cos\theta_p < 0.0$ to the cross section of ※1.

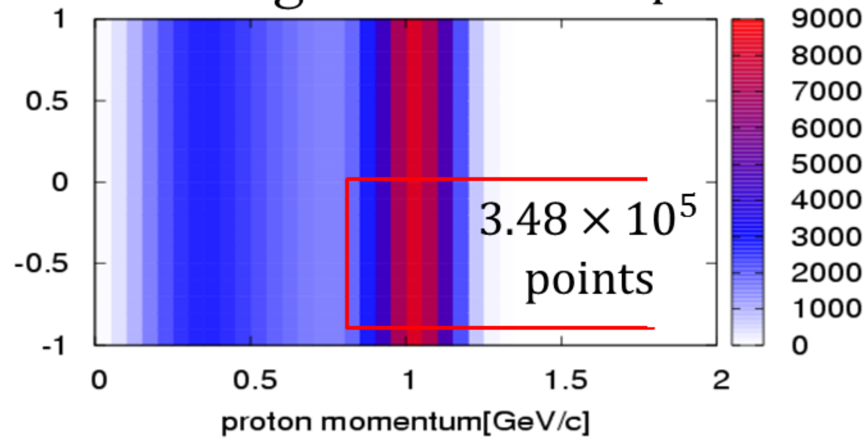
$$\int dE_d \int_{0.8[GeV/c]}^{\infty} dP_p \int_{-0.9}^{0.0} 2\pi d(cos\theta_p) \times \frac{d^4\sigma}{d\Omega_d dE_d d\Omega_p dP_p}$$

3.Discussion : Comparison of Signal with Background (obtained by independent simulations)

Background $(1.06 \times 10^6$ points$)$



Signal $(1.0 \times 10^6$points$)$



	Inclusive(p,d) $\frac{d\sigma}{d\Omega_d}$ ※1	proton cut $\frac{d\sigma}{d\Omega_d}$ ※2
Background	760 [μb/sr] $\xrightarrow{\times \frac{3736}{1.06 \times 10^6}}$	2.68 [μb/sr]
Signal	1.1 [μb/sr] $\xrightarrow{\times \frac{3.48 \times 10^5}{1.0 \times 10^6}}$	0.38 [μb/sr]
S/N ratio	1.4×10^{-3}	1.4×10^{-1}

The S/N ratio is improved by the factor of 100.

4, summary

- η' mesic nucleus is an interesting object and is planned to be investigated experimentally.
- We performed the numerical simulation by using JAM to improve the S/N ratio of the η' formation reaction.
- **The S/N ratio is improved by the factor of 100 by the kinematical conditions of $\left|\overrightarrow{P_p}\right|$ > 0.8GeV/c and -0.9 < cos θ_p < 0.0 in the $^{12}\mathrm{C}(p, d)\ p\ X$ reaction.**
- As future works, we will consider better conditions for semi-exclusive measurements.