# Probing neutron halo structure of $^{6}$He nucleus by the measurement of $\pi$ meson

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# $\pi$ meson as new probe for RI ~~ sensitive to isospin ~~

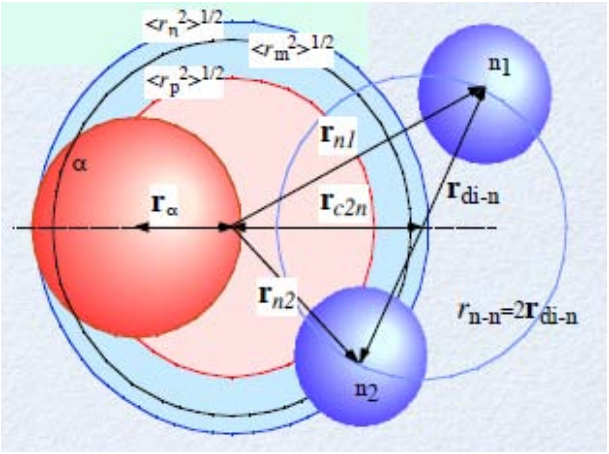
- If proton is target:
- $\pi^0$ is good probe for neutron matter (surface).
  - $\sigma(p+n\rightarrow\pi^0+X) : \sigma(p+p\rightarrow\pi^0+X) = 4:1$ according to brief calculation.
    - Only the effect from isospin restriction is taken into account.
  - $\sigma(p+n\rightarrow\pi^0+X) : \sigma(p+p\rightarrow\pi^0+X) =$ **20:1** according to experimental data.
  - Detected $\pi^0$ can be treated as coming from p+n collisions.
- $\pi^+$ is good probe for proton matter (surface).
  - $\sigma(p+n\rightarrow\pi^++X) : \sigma(p+p\rightarrow\pi^++X) = 1:5$
  - Phys. Rev. C 20 (1979) 1332
- Note: nuclear absorption in nucleus has to be taken into account.

# Physics Motivation

- To study the dineutron correlation bounded in various halo nucleus.
  - core + two neutron haloes is major model to describe experimental data.
  - $^{6}$He, $^{11}$Li are first target nuclei.
- Laser spectroscopy of $^{6}$He gave us strong information for its structure.
  - PRL 93 (2004) 142501
- Spacial dineutron correlation in $^{11}$Li was indicated through the measurement of E1 excitation in Coulomb dissociation.
  - PRL 96 (2006) 252502
  - The existence of a virtual s state in the residual $^{10}$Li nucleus is expected in Coulomb break up.
    - PRC 80 (2009) 031301
- New probe for the study of such exotic state is necessary to understand the dineutron correlation.

# Distance between neutron haloes in $^6$He.

- Distance between two neutron haloes in $^6$He can be estimated based on the matter radius and charge radius.
  - Model: core + two neutron haloes.
  - Core nucleus is assumed to be intact.
- Information of dineutron correlation will give the information for core nucleus in halo nucleus.

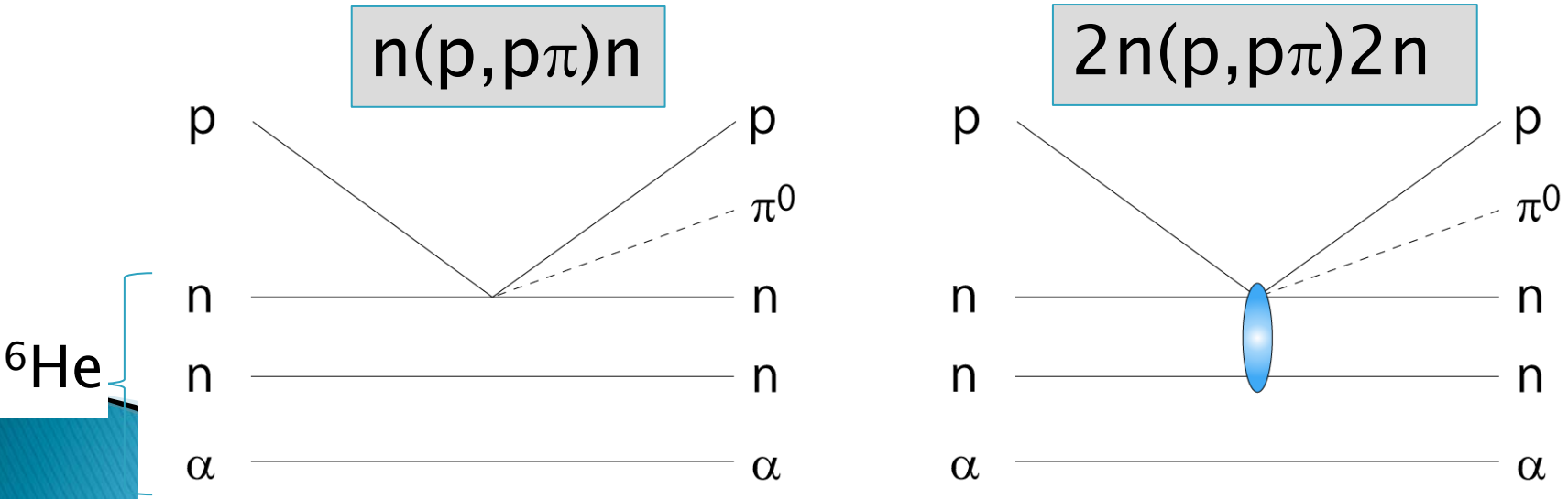



**I. Tanihata, Halo2010**

| | Experiment [fm] | 3-body. [fm] | Varga [fm] | Esbensen [fm] | Funada [fm] | Zhulov [fm] |
|---|---|---|---|---|---|---|
| $\langle r_m^2\rangle^{1/2}$ | 2.43±0.03 | 2.48 | 2.46 | | | 2.45 |
| $\langle r_p^2\rangle^{1/2}$ | 1.912±0.018 | | 1.80 | | | |
| $\langle r_n^2\rangle^{1/2}$ | 2.65±0.04 | | 2.67 | | | |
| $\langle r_n^2\rangle^{1/2}$-$\langle r_p^2\rangle^{1/2}$ | 0.808±0.047 | | 0.87 | | | |
| $\langle r_{2n}^2\rangle^{1/2}$ | 3.23±0.07 | | 3.42 | | | |
| $\langle r_{(\alpha\text{-}2n)}^2\rangle^{1/2}$ | 3.84±0.06 | 3.606 | | 3.592(3.63) | 3.51 | 3.54 |
| $\langle r_{n\text{-}n}^2\rangle^{1/2}$ | 3.93±0.25 | 4.762 | | 5.413(4.62) | 4.55 | 4.58 |
| $\langle \mathbf{r}_{n1}\mathbf{r}_{n2}\rangle$ [fm$^2$] | 2.70±0.97 | 0.110 | | -1.59(0.54) | 0.292 | 0.325 |

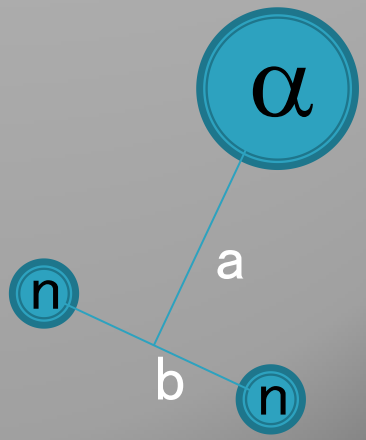
# π meson as a probe of halo nucleus

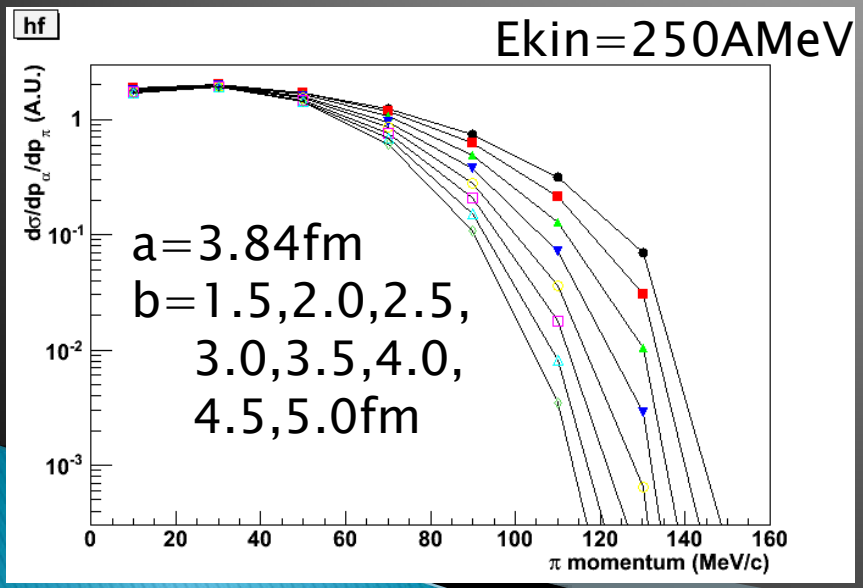
- π meson is expected to be useful as new probe for halo nucleus.
  - Large momentum transfer is necessary for the production.
- Its production sensitive to the spacial information among neutron haloes and core nucleus.
  - Wave-function of neutrons are overlapped.
  - π production kinematics is expected be dramatically changed in the case of p+{2n} comparing with p+n.
  - Especially around threshold energy for π production.

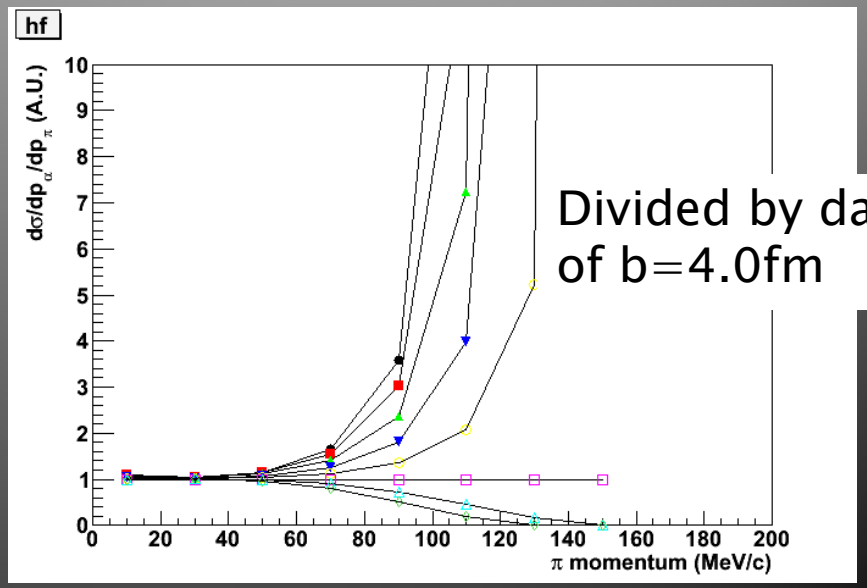


# Theoretical calculation of π meson production in $^6$He+p.

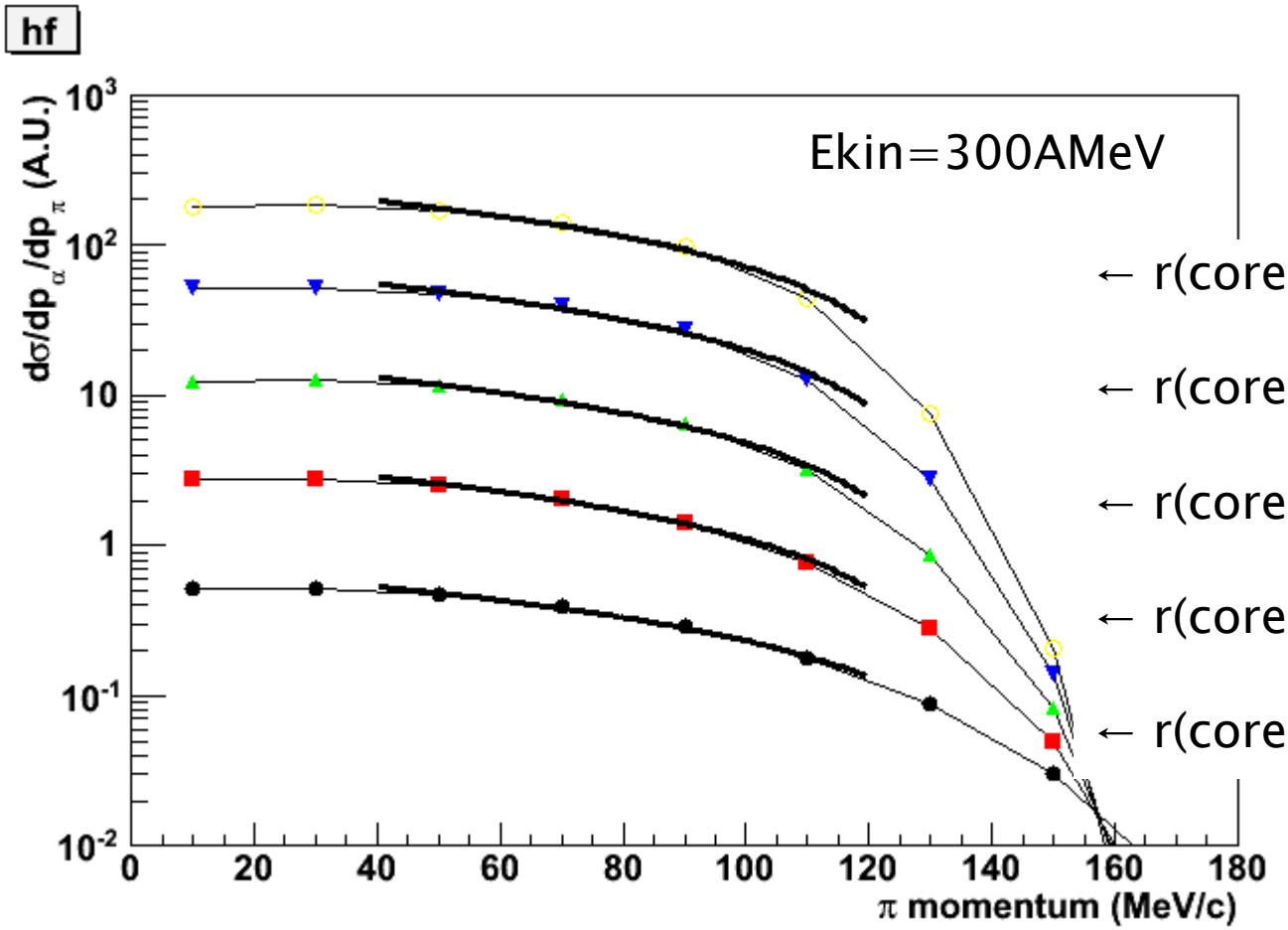
- T-Matrix accounts for overlapping of wave-function of dineutron.
- Momentum spectra of produced π meson is evaluated.
  - High-momentum π meson strongly depends on spacial correlation.
  - High intensity beam is necessary.



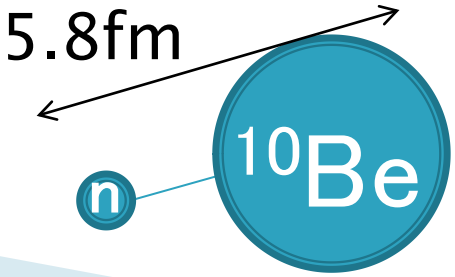



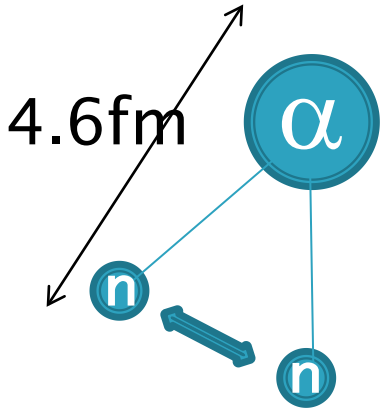
# If the core of $^{6}$He is not intact.



# Idea on the experiment

- Measure the $\pi$ mesons produced in N+{neutron halos} collisions.
  - Measurement of neutral $\pi$ meson will avoid the systematic error from Coulomb effect.
- Events where target nucleon hits the haloes have to be identified somehow.
  - Identify the spectator of collision using spectrometer.
- In addition to $^{6}$He+N, experiment of $^{11}$Be+N is expected to be necessary as reference data of n+N process in A+N system.

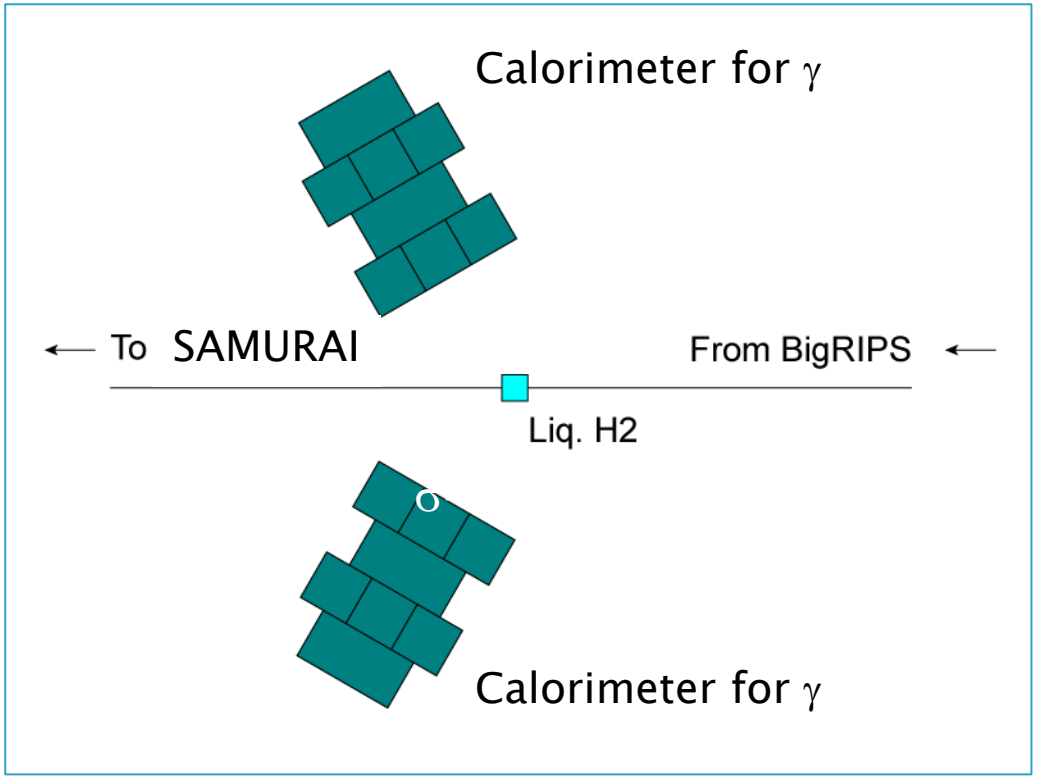


# Experimental setup

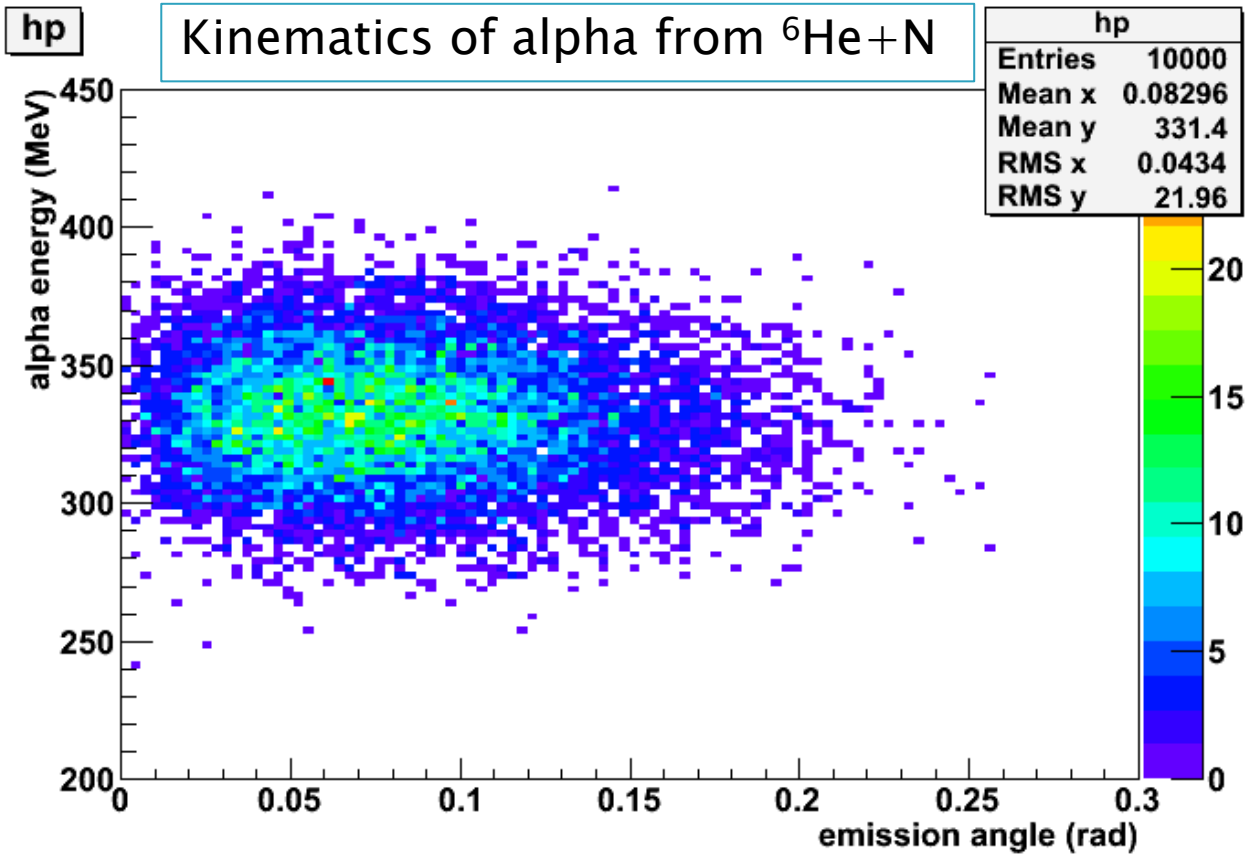
- Measure the $\pi$ mesons produced at liq. $H_2$ target.
  - Use $\pi^0 \rightarrow 2\gamma$ decay mode.
  - Calorimeter for $\gamma$.
- Events (spectator) will be characterize with following spectrometer.

  →SAMURAI



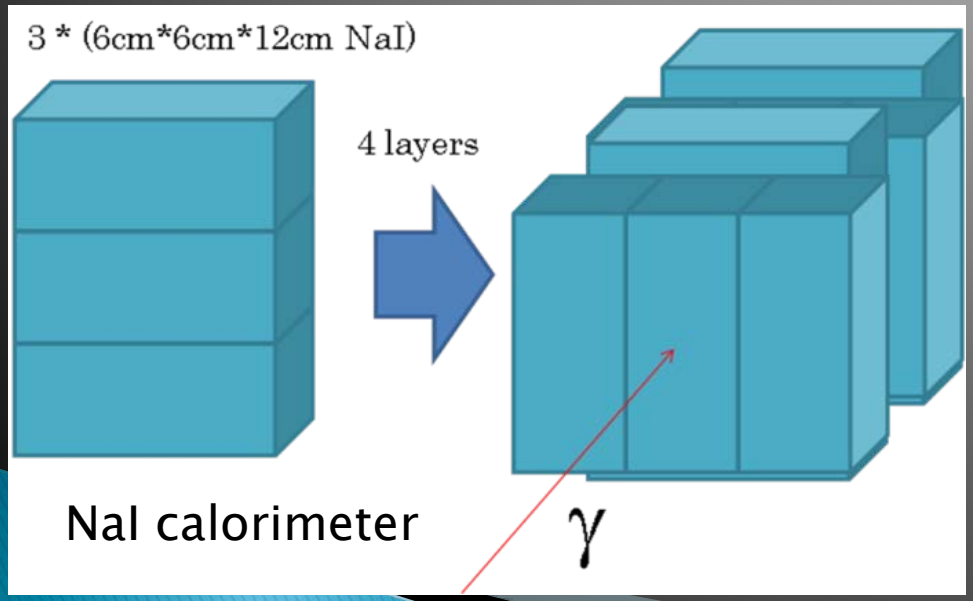
# SAMURAI for the identification of spectator

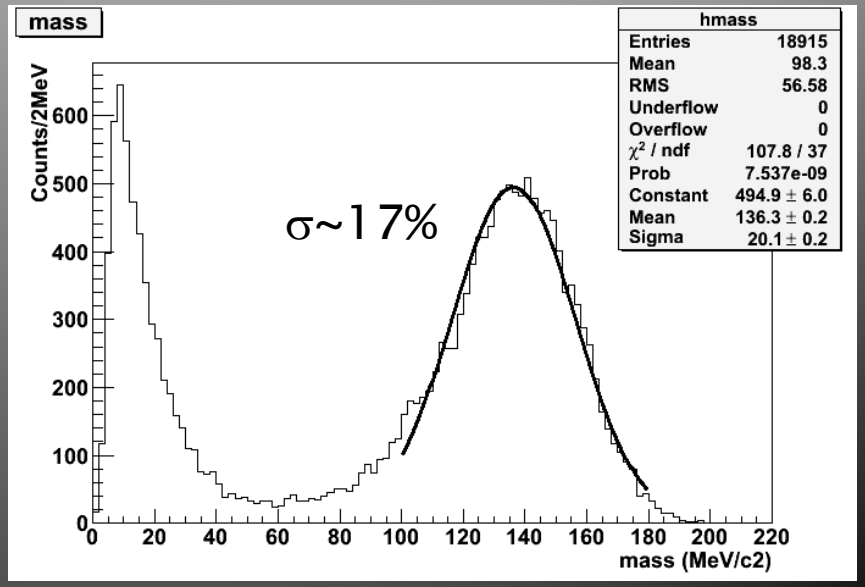
- Due to the Fermi motion of spectator, a large acceptance spectrometer is necessary.
- Identify $^{4}$He and $^{6}$He.



# Electromagnetic Calorimeter for the measurement of gamma from $\pi^0$

- Electromagnetic calorimeter has to be developed.
  - To measure ~100MeV gamma from $\pi^0$s.
- Combination of multiple NaI scintillator is planned.
- Pure CsI is better for the experiment with higher rate beam.




MC result of $\pi^0$ mass distribution

# Summary

- $\pi$ meson is useful as a probe for the dineutron correlation in halo nucleus.
- SAMURAI spectrometer is necessary to perform the experiment at RIBF.
  - For the identification of spectator.
- Establish the experimental method though the study of $^{6}$He.

- Experimental study of $^{11}$Li is interesting, since $^{9}$Li in $^{11}$Li might not be intact.
- Correlation between four neutrons in $^{8}$He would be probed.