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New Results on Photodisintegration of ^{4}He

Tatsushi Shima

Research Center for Nuclear Physics, Osaka University

- Motivation for study of ^{4}He photodisintegration
- Experimental method; LCS-γ beam + TPC (active target)
- Result
- Summary

Collaborators

Y. Nagai

Nuclear Science and Engineering Directorate,
Japan Atomic Energy Agency

H. Utsunomiya, H. Akimune

Department of Physics, Konan University

T. Mochizuki, S. Miyamoto, K. Horikawa

Laboratory for Advanced Science and Technology for Industry,
University of Hyogo

M. Fujiwara

Research Center for Nuclear Physics, Osaka University

Motivation for experimental study of ^{4}He photodisintegtration

- Long-standing problem; CSB in nuclear force?

$$\sigma\left({}^4He(\gamma,p){}^3H\right)/\sigma\left({}^4He(\gamma,n){}^3He\right)\cong 1?$$

- Test of theoretical models for 4N system

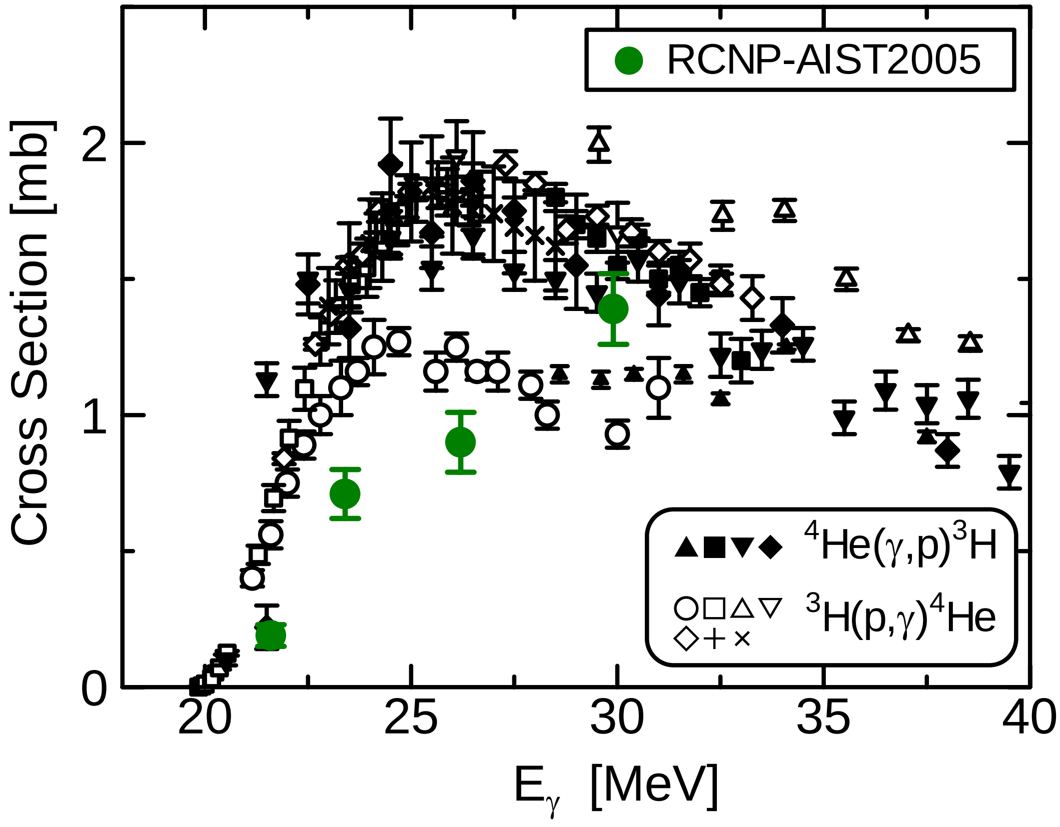
- Information about ^{4}He(ν,ν') in Type-II supernovae and r-process nucleosynthesis in ν-driven wind

- Post-processing on primordial elements by delayed γ from decay of long-lived exotic particle; Kusakabe et al. PRD79, 123513 (2009)

Previous works; $^{4}He(\gamma,p)^{3}H$ & $^{3}H(p,\gamma)^{4}He$

(detailed balance)

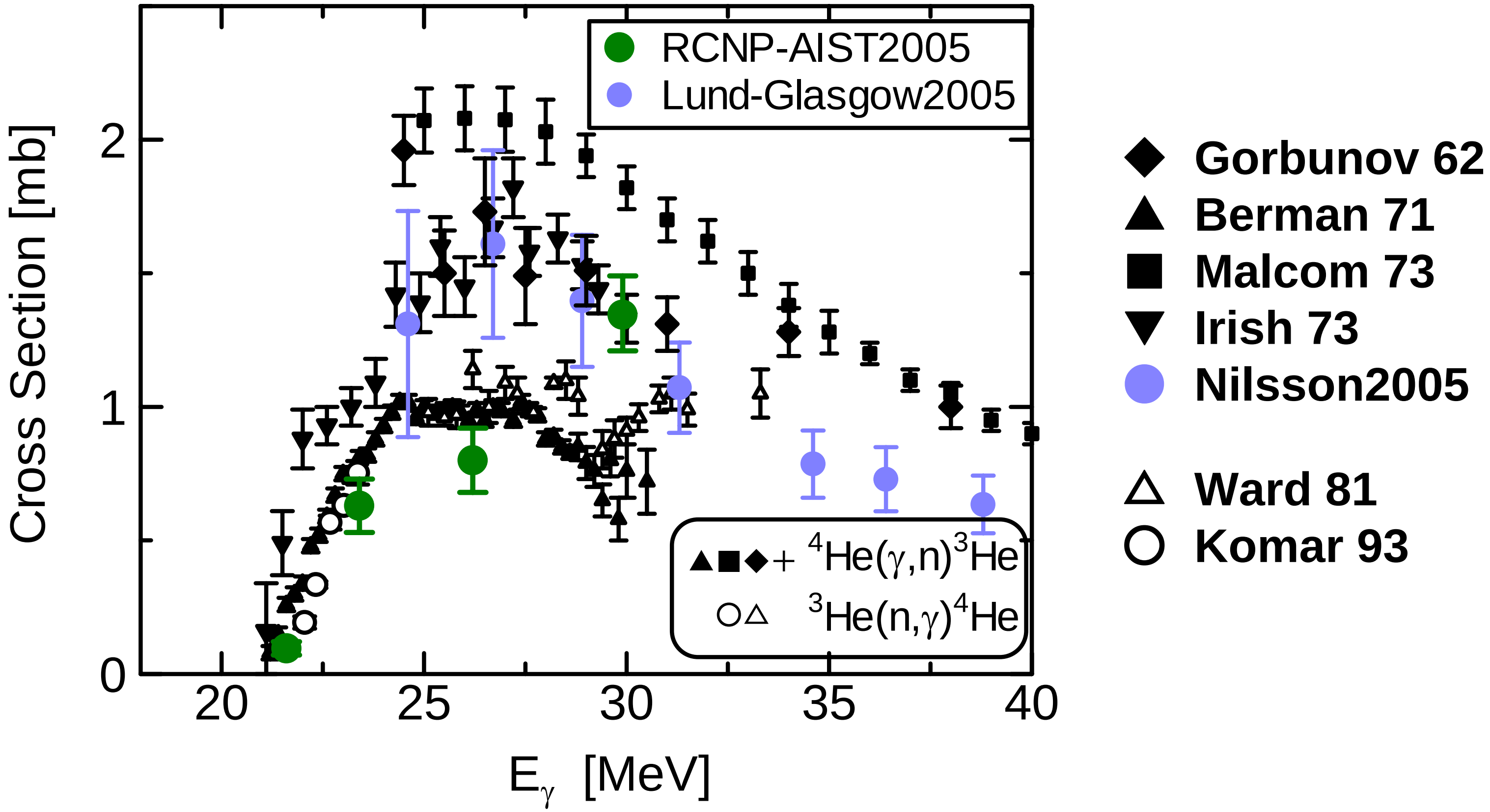
PRC72, 044004 (2005)



- ◆ Gorbunov 62
- ▼ Arkatov 78
- ▲ Bernabei 88
- ■ Hoorebeke 93
- + Gardner 62
- × Gemmell 62
- ◇ Meyerhof 70
- △ McBroom 82
- ▽ Calarco 83
- ○ Feldman 90
- □ Hahn 95

Previous works; $^4He(\gamma,n)^3He$ & $^3He(n,\gamma)^4He$

(detailed balance)

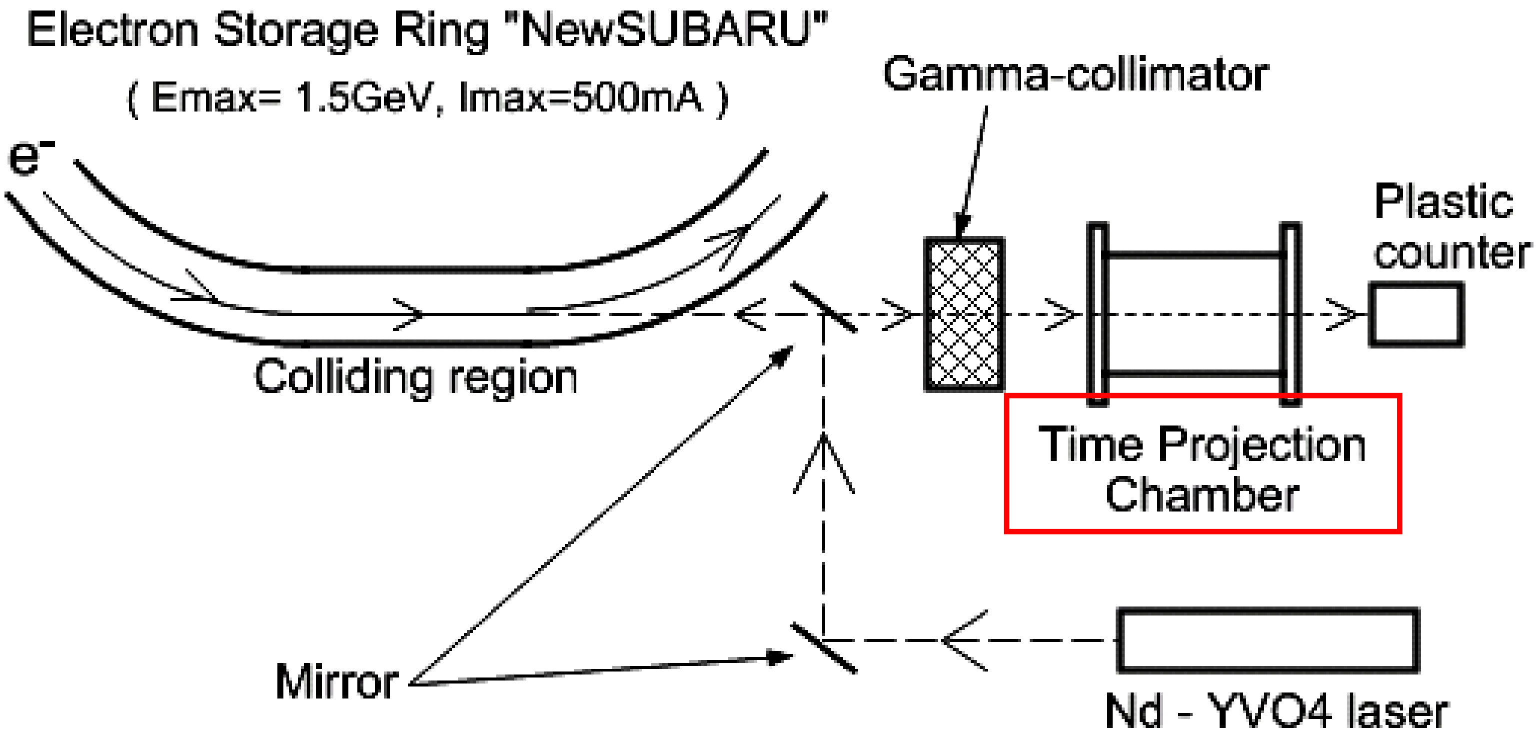


* AIST --- National Institute of Advanced Industrial Science and Technology (Tsukuba, Japan)

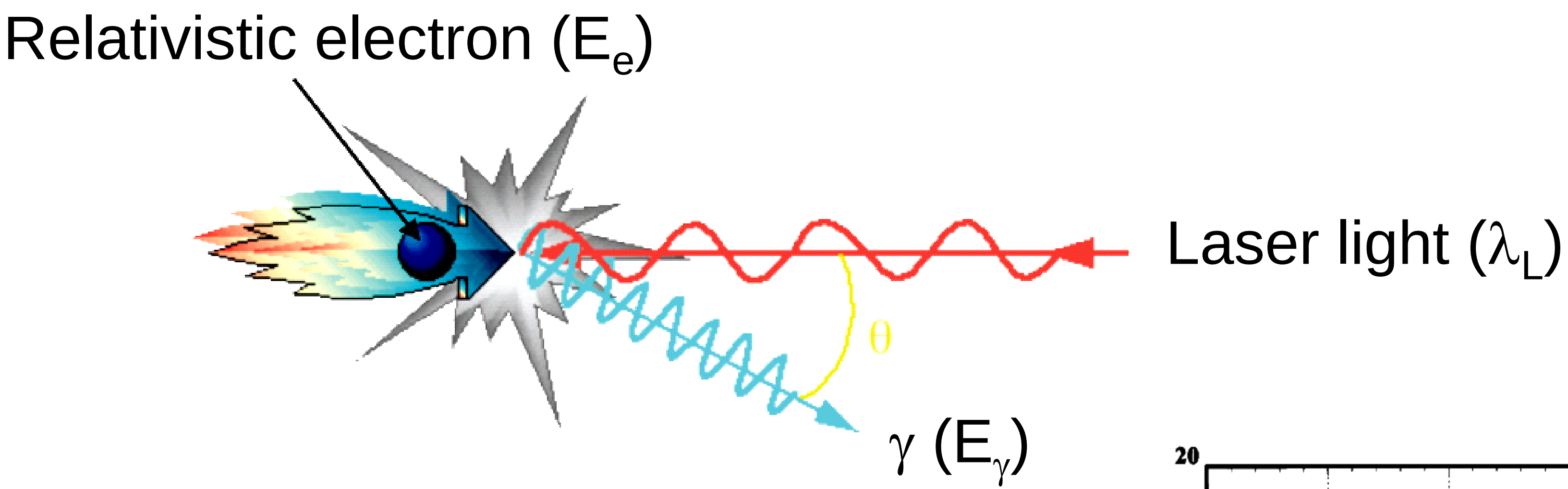
Experiment with quasi-monochromatic γ at NewSUBARU

Laser Compton-scattered γ-ray :

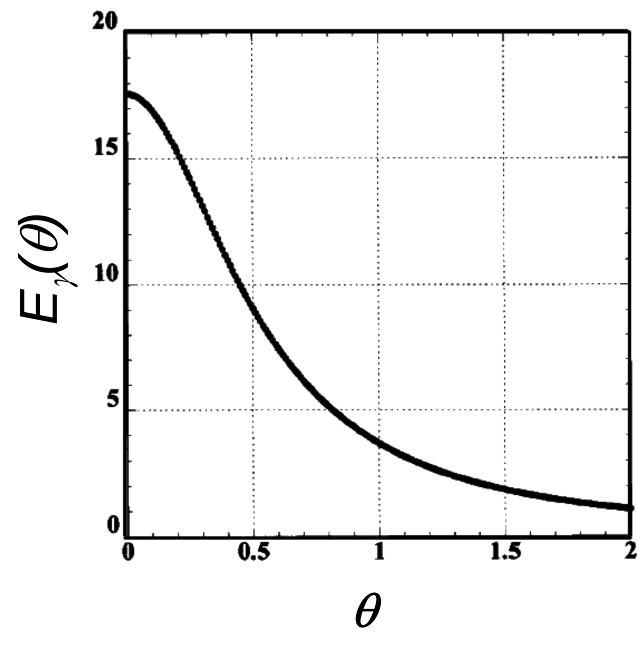
E_γ = 16 ~ 40MeV, Φ_γ ~2×10^4 /sec, FWHM~9%, P~100%



Laser Compton-scattered γ (LCS-γ)



$$E_\gamma = \frac{4hc}{\lambda_L} \cdot \frac{\gamma^2}{1+\gamma^2\theta^2}, \qquad \gamma = \frac{E_e}{m_e c^2}$$



λ_L=1.064μm, E_e=800MeV ⇒ E_γ = 11MeV

λ_L=1.064μm, E_e=1.5GeV ⇒ E_γ = 39MeV

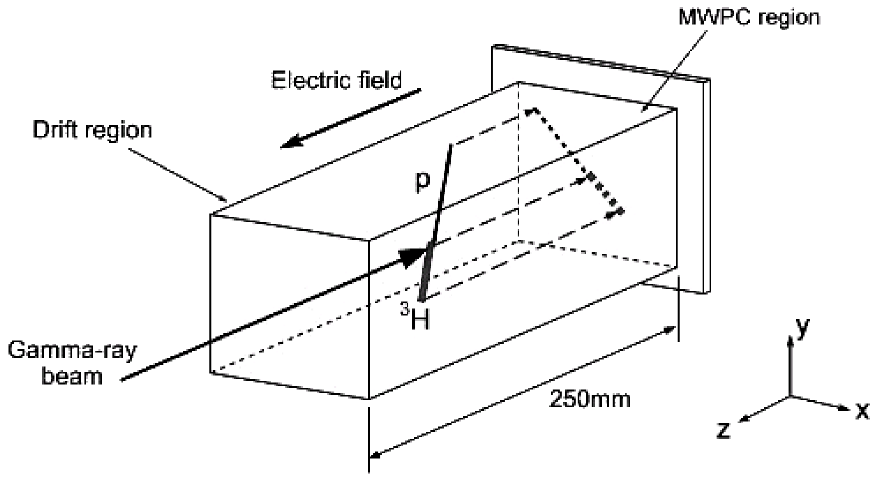
Advantages of LCS-γ

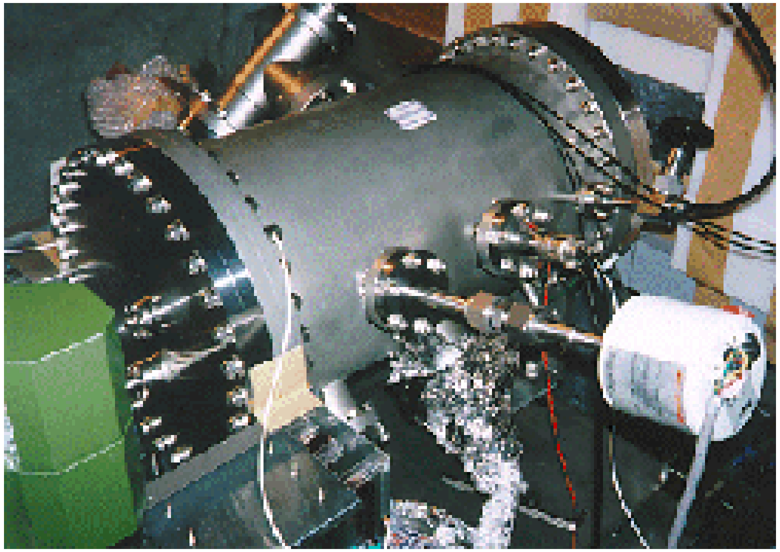
- Quasi-monochromatic; $\Delta E/E$ ~ a few %
- Little low-energy BG, good S/N
- Well-collimated; $\Delta\theta < 0.1$ mrad
- Highly polarized; linear or circular, P ~ 100%
- Continuous or pulsed; $\Delta t < 10$ns

NewSUBARU

Lab. of Adv. Sci. and Tech. for Industry, University of Hyogo, Japan

Time Projection Chamber





TPC gas : He $+CH_4$ (CD_4) ; active target

- $\Omega \sim 4\pi$, ε ~100%

  → little uncertainties in detector sensitivity
- track shape, dE/dx → reliable event ID
- capability to simultaneous measurements of two-body and multi-body reaction channels

Cross section:

$$Y_i = \varepsilon_i \cdot N_{4He} \cdot \sigma \cdot \Phi_\gamma = \varepsilon_i \cdot N_{4He} \cdot \sigma \cdot \frac{Y_\gamma}{\varepsilon_\gamma}$$

$$\Rightarrow \quad \sigma = \frac{Y_i}{\varepsilon_i \cdot N_{4He}} \cdot \frac{\varepsilon_\gamma}{Y_\gamma}$$

Y_i : Yield of reaction channel *i*

Y_γ : Count of γ-ray flux monitor

ε_i : Detector efficiency for reaction channel *i*

ε_γ : Detection efficiency of γ-ray flux monitor

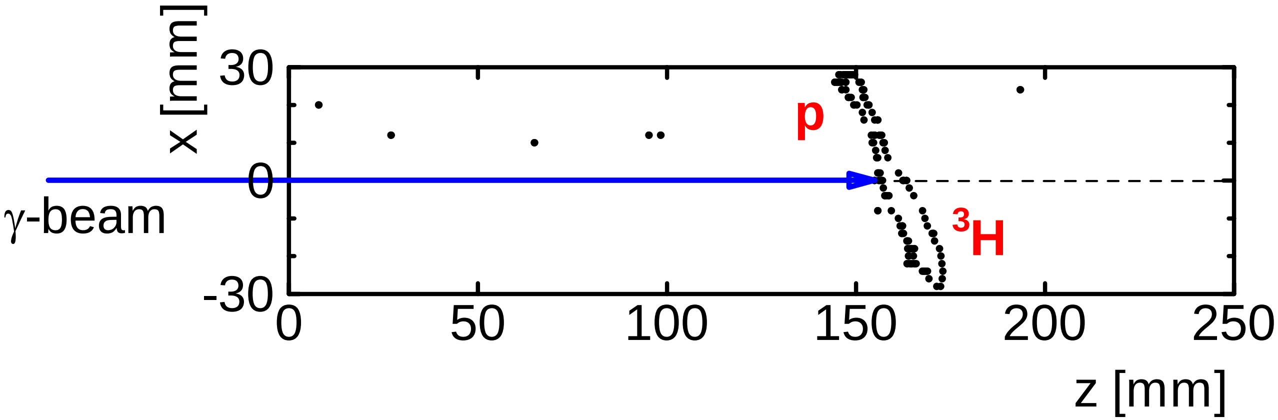
N_{4He} : target density

- event ID $\Rightarrow Y_i$
- Detection efficiency of TPC $\Rightarrow \varepsilon_i$
- Detection efficiency of γ-ray monitor $\Rightarrow \varepsilon_\gamma$

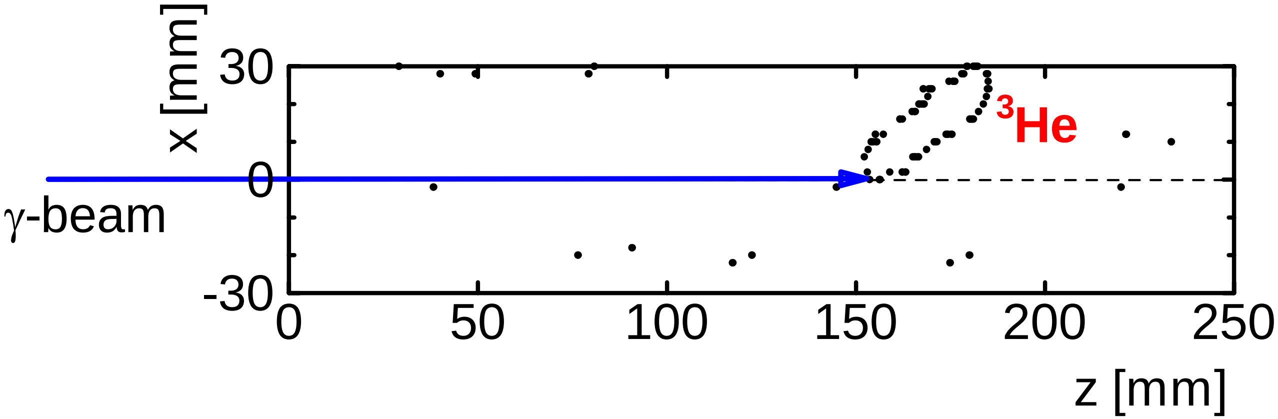
Event ID by topology

- Vertex position ; true ⇔ background
- Number of tracks ; (γ,p) ⇔ (γ,n) ⇔ $(\gamma,2\alpha)$
- Track length ; p, d, ^3He, ^4He ⇔ ^{11}B, ^{11}C
- dE/dx ; p, d ⇔ ^3He, ^4He
- Track angle ; two-body decay ⇔ multi-body decay

Examples of track image

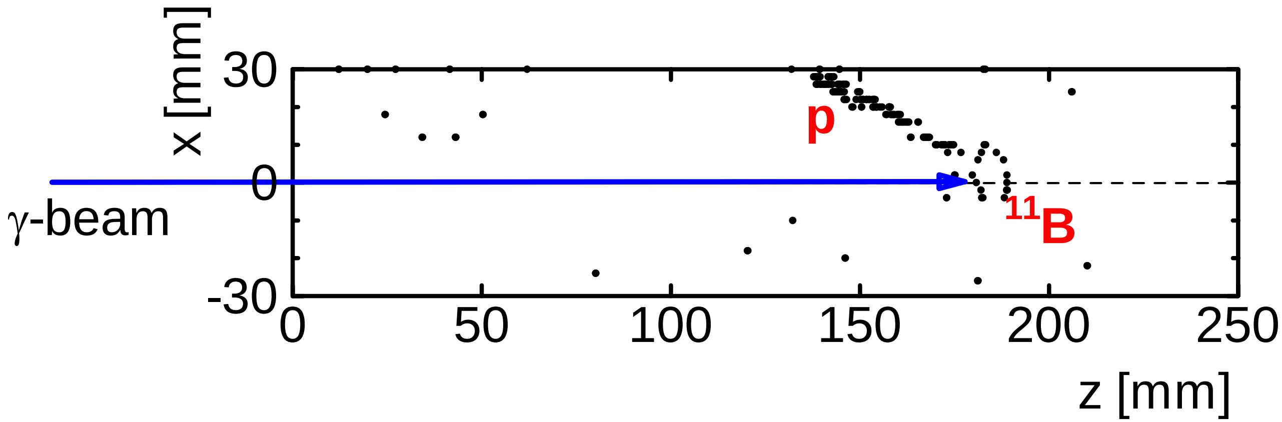


$^4He(\gamma,p)^3H$

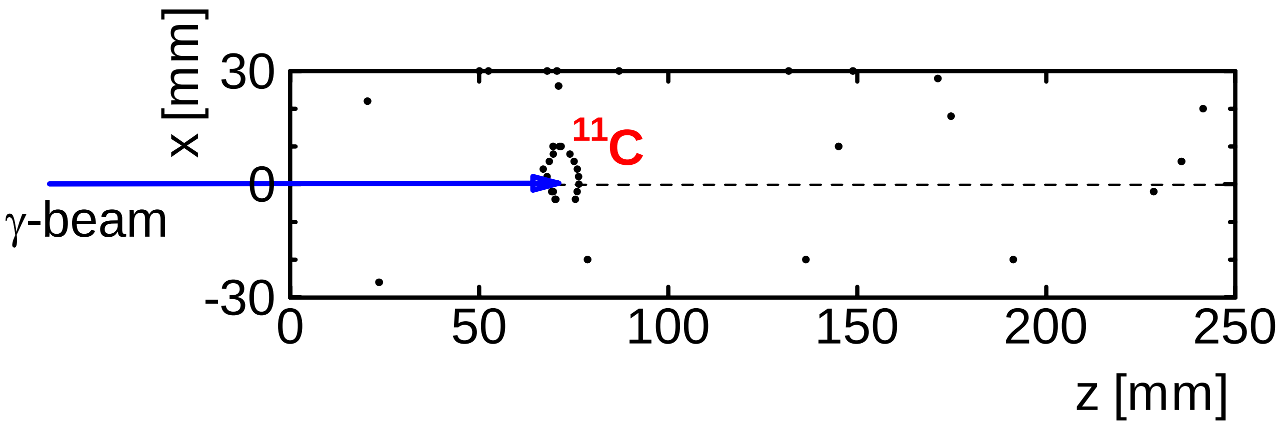


$^4He(\gamma,n)^3He$

^{12}C photodisintegrations

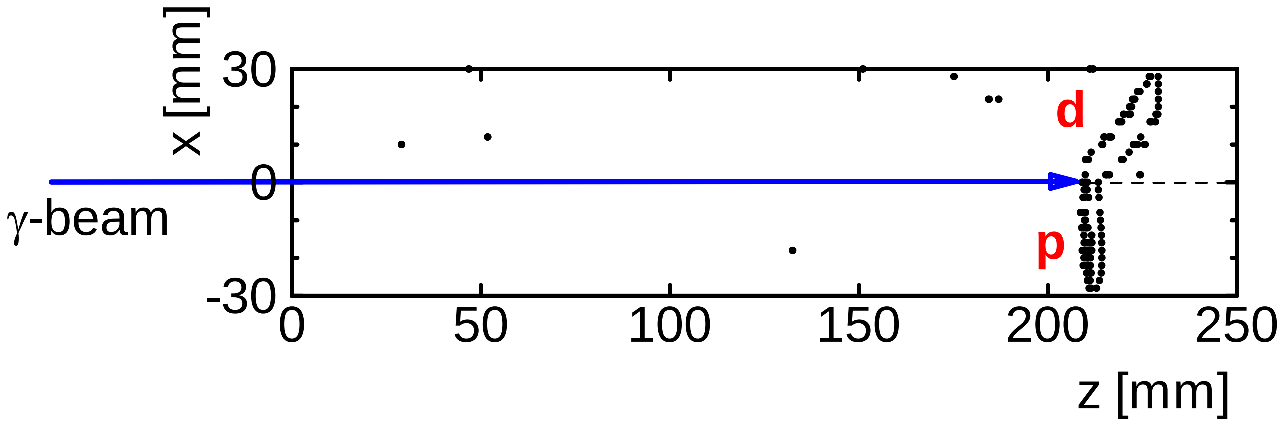


$^{12}C(\gamma,p)^{11}B$

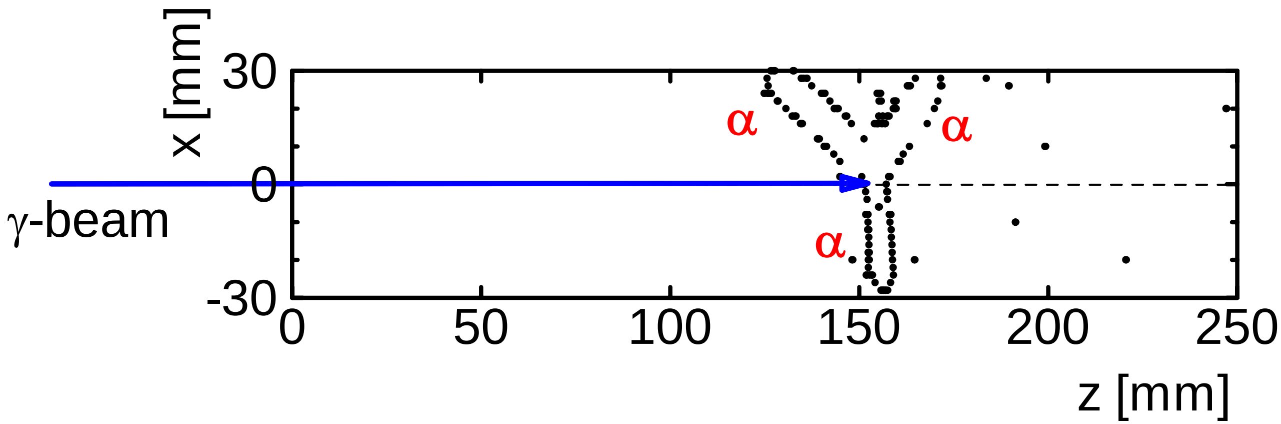


$^{12}C(\gamma,n)^{11}C$

Three-body decays

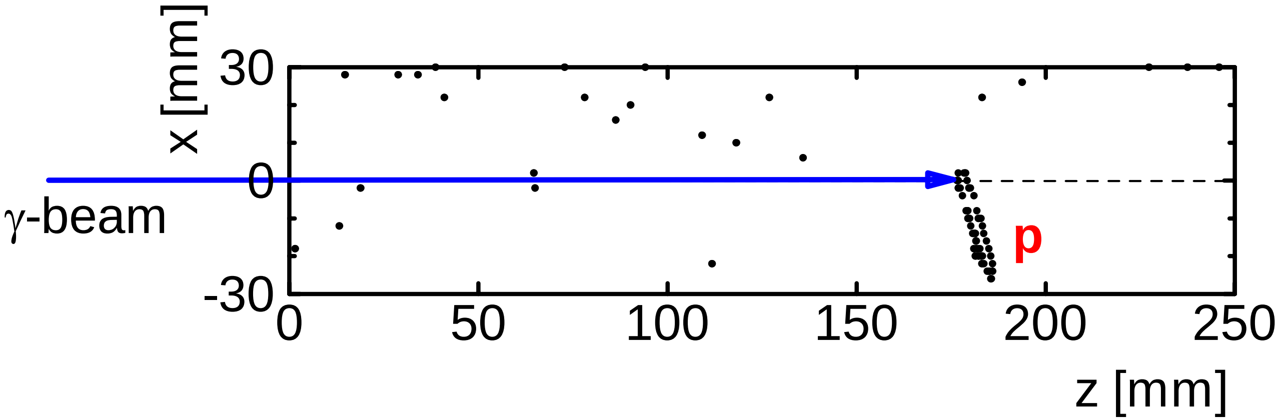


$^4He(\gamma,pn)^2H$



$^{12}C(\gamma,2\alpha)^4He$

D(γ,n)p



Detection Efficiency of TPC

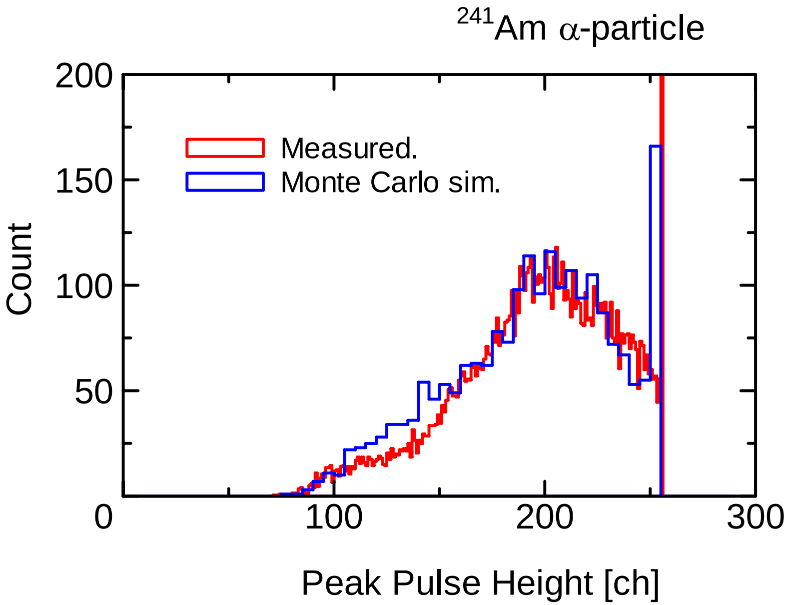
A precise Monte Carlo code was developed to check the responses of the TPC. The code includes the following effects;

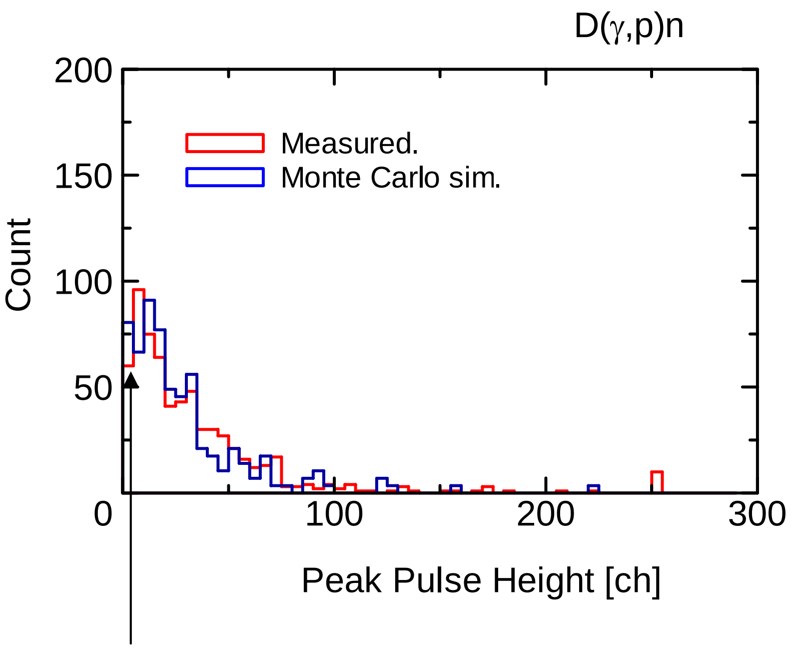
- Energy and angular distributions of the incident γ-ray beam
- Energy and angular dependences of the reaction cross sections
- Energy loss of the photo-emitted charged particles in the TPC gas
- Statistical fluctuation of electron multiplication process
- Transport of ionized electrons from track position to anode plane
- Electrical property of amplifiers for wire signals and DAQ
- Efficiency of the cuts in the off-line analysis

Pulse height spectra of charged particles

^{241}Am α-particle

D(γ,p)n

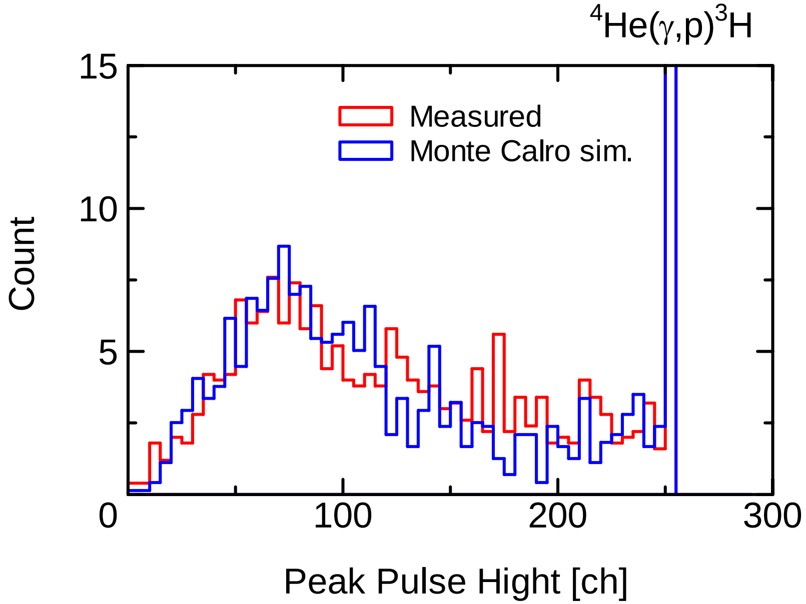




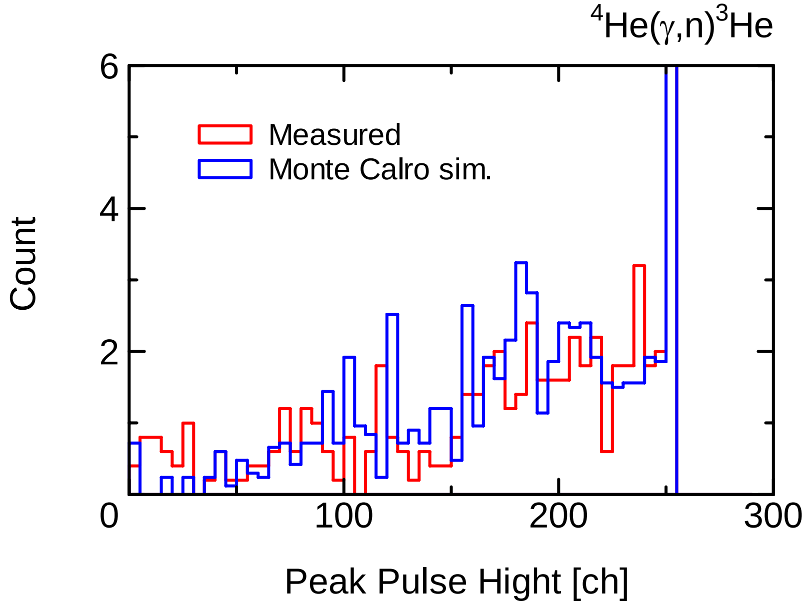
Threshold: 7.0±0.7ch

ε = 0.69±0.04

$^{4}He(\gamma,p)^{3}H$

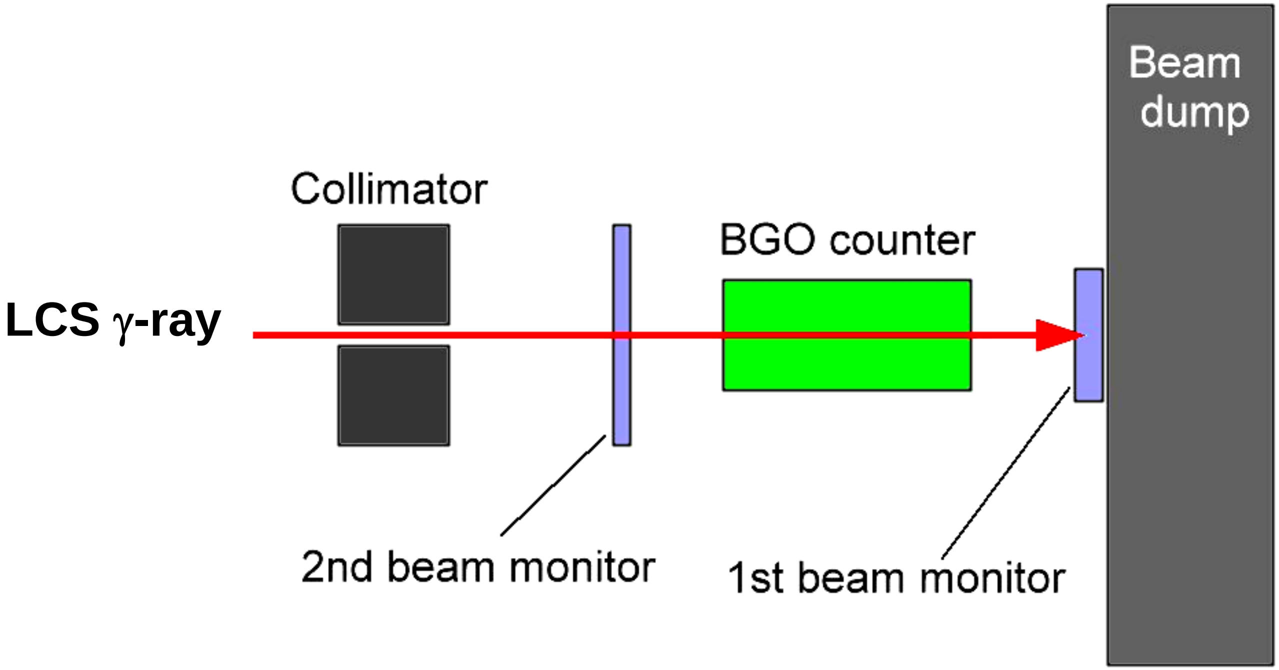


$^{4}He(\gamma,n)^{3}He$



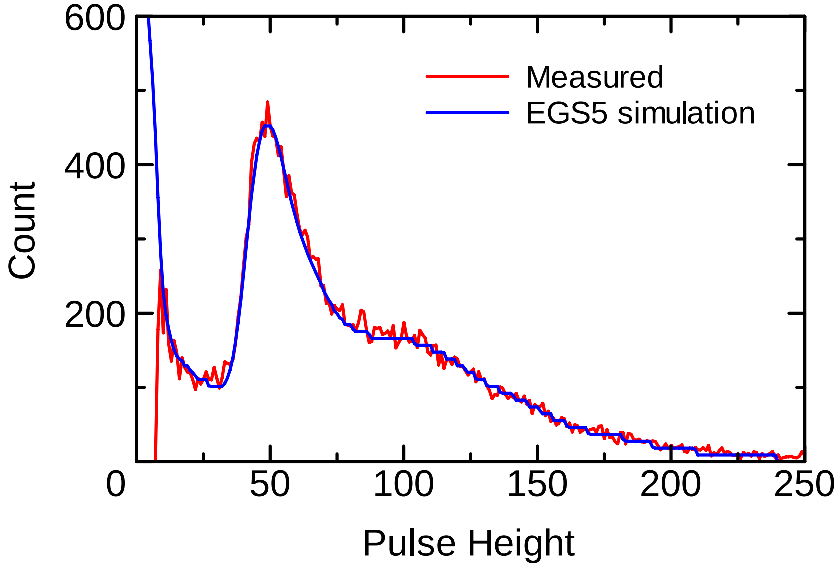
$\varepsilon > 0.985$

Calibration of γ-ray flux monitor by BGO counter

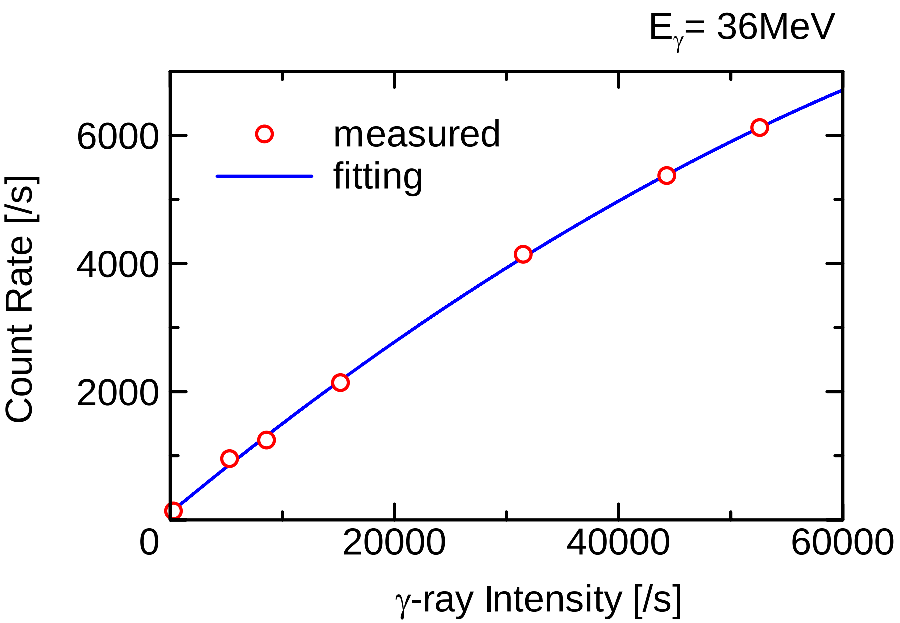


The absolute efficiency of the first beam monitor was calibrated with respect to the BGO counter (ε=100%) using the second beam monitor for normalization.

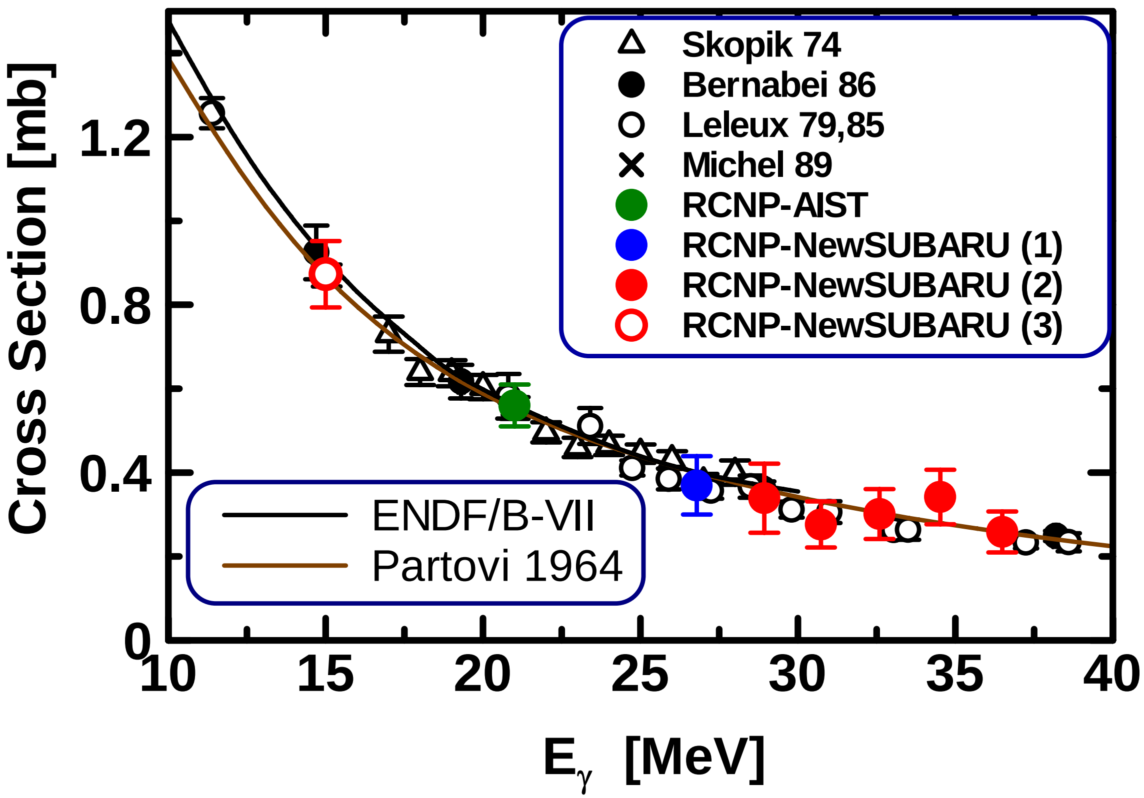
Pulse height spectrum of
γ-ray flux monitor (10mm plastic scint.)



Incident γ-ray intensity
v.s. counting rate

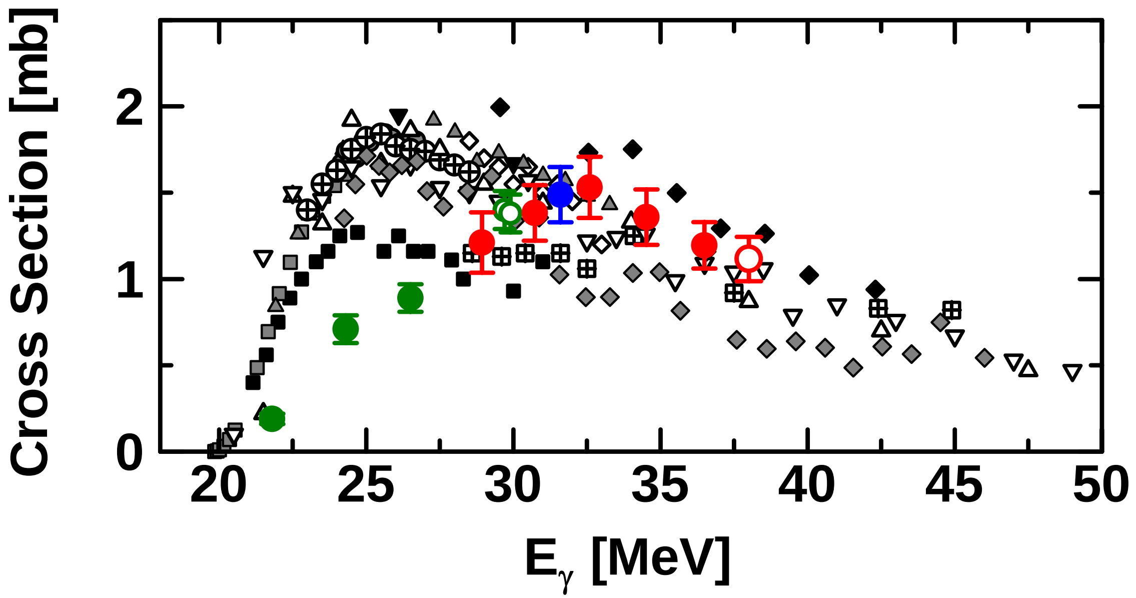


D(γ,p)n (preliminary)



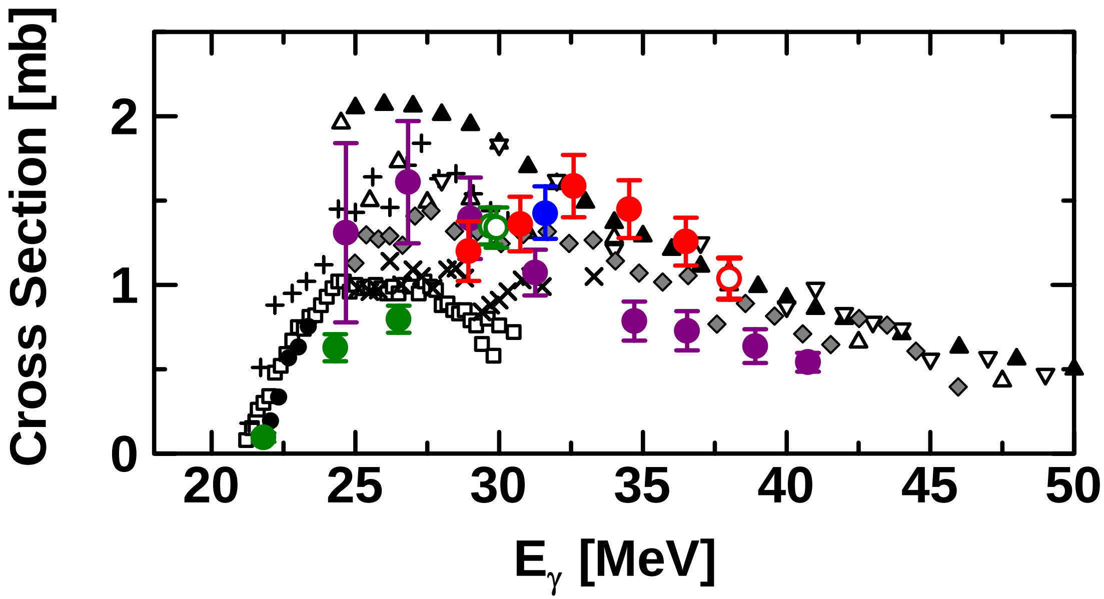
--- New data are in good agreement with existing ones as well as theoretical calculations and fittings.

$^4He(\gamma,p)^3H$ (preliminary)



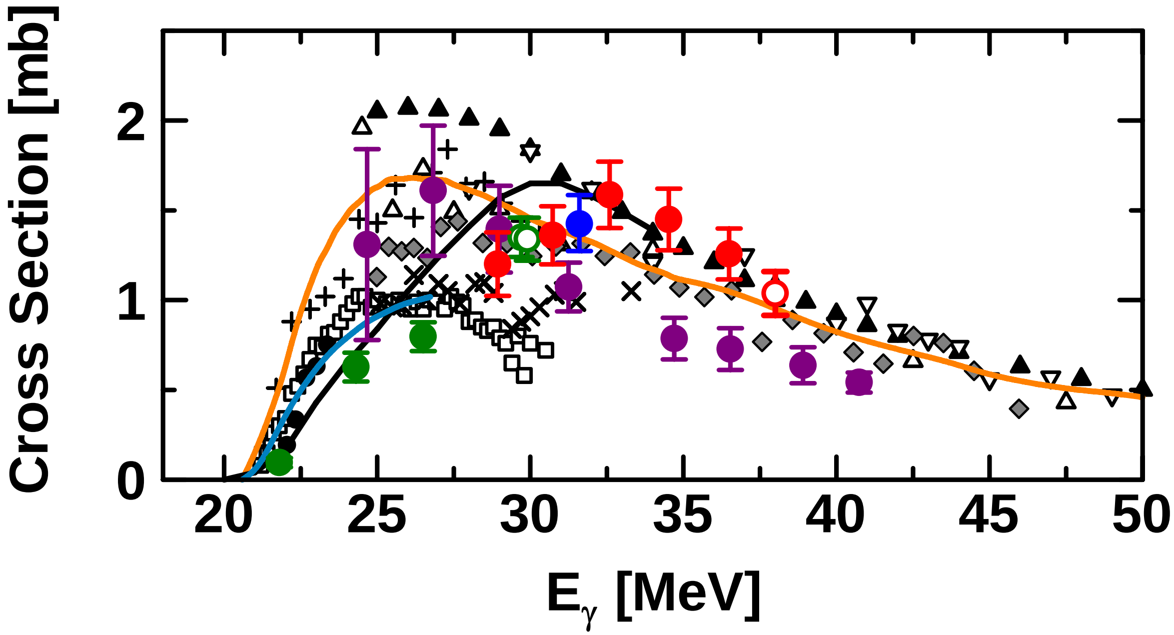
- ● RCNP-AIST2005 (PRC72, 044004) ; λ=351nm (3rd), E_e=0.8GeV
- ● RCNP-NewSUBARU; λ=532nm (2nd), E_e=0.97GeV
- ● RCNP-NewSUBARU; λ=1064nm (fund.), E_e≤1.46GeV
- ○ RCNP-NewSUBARU; λ=532nm (2nd), E_e=1.06GeV

$^4He(\gamma,n)^3He$ (preliminary)



- RCNP-AIST2005 (PRC72, 044004) ; λ=351nm (3rd), E_e=0.8GeV
- RCNP-NewSUBARU; λ=532nm (2nd), E_e=0.97MeV
- RCNP-NewSUBARU; λ=1064nm (fund.), E_e≤1.46GeV
- RCNP-NewSUBARU; λ=532nm (2nd), E_e=1.06GeV
- Lund 2005-2007 (PRC75, 014007) ; tagged photons

$^4He(\gamma,n)^3He$ (preliminary)



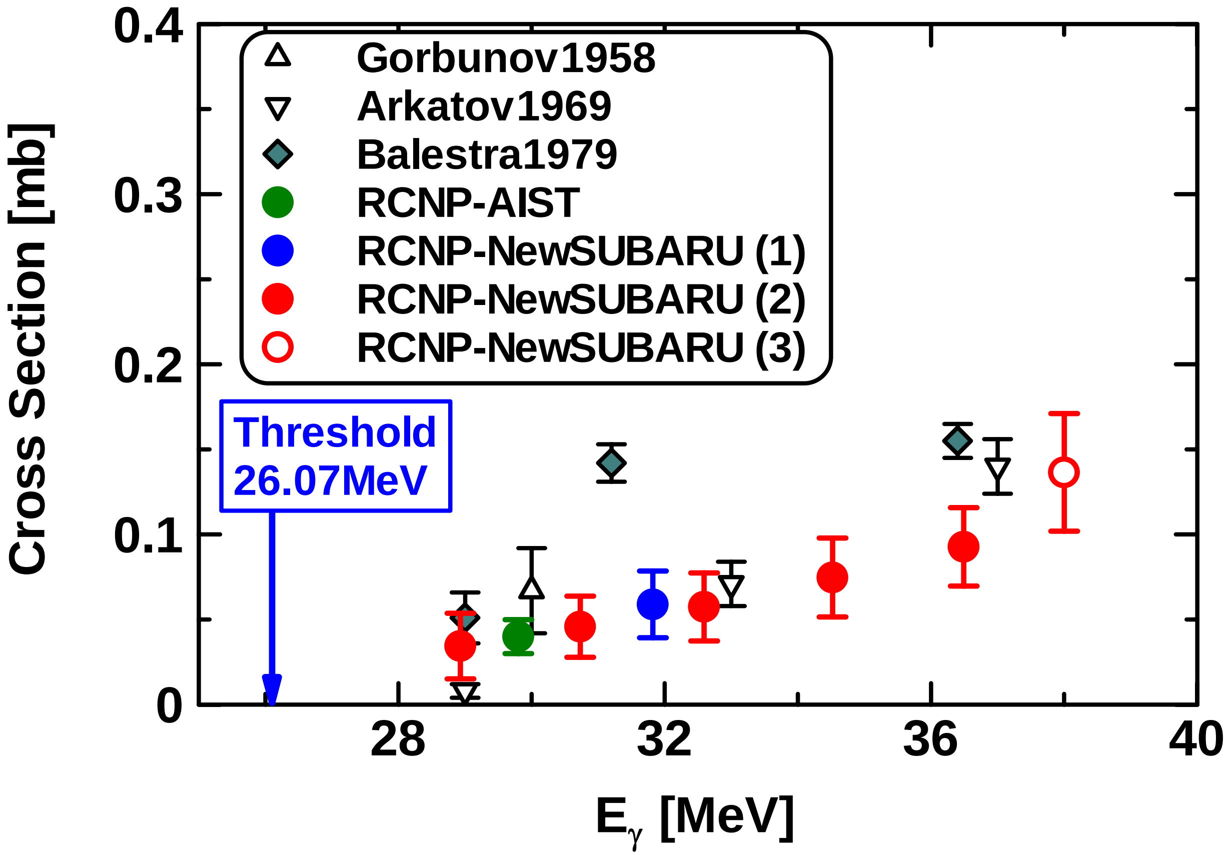
RCNP-AIST RCNP-NewSUBARU Lund 2005-2007

Trento (Lorentz-Integral-Transform) ; PR C69 044002 (2004)

Bonn (Faddeev-AGS) ; NP A631 210c (1997)

Londergan-Shakin (C.C. Shell Model) ; PRL28 1729 (1972)

$^4He(\gamma,pn)d$ (preliminary)



Summary

- Cross sections of 2-body and 3-body photodisintegrations of ^{4}He was measured up to E_γ =38MeV, using the NewSUBARU LCS γ-ray beam and the TPC filled with an active target gas made of He-CD_4 mixture.

- Main sources of the systematic errors have been carefully studied from comparison of the calibration data and the Monte Carlo simulations;

  δ(TPC)<1.5% for ^{4}He, 6% for D and δ(γ-flux)<5%

- We are planning to do
  - measurement of photonuclear reaction cross sections of ^{3}He
  - measurement of ^{4}He(γ,n) cross section using neutron detector

--- Stay tuned !