
Search for Rare γ -decay Modes in ^{12}C

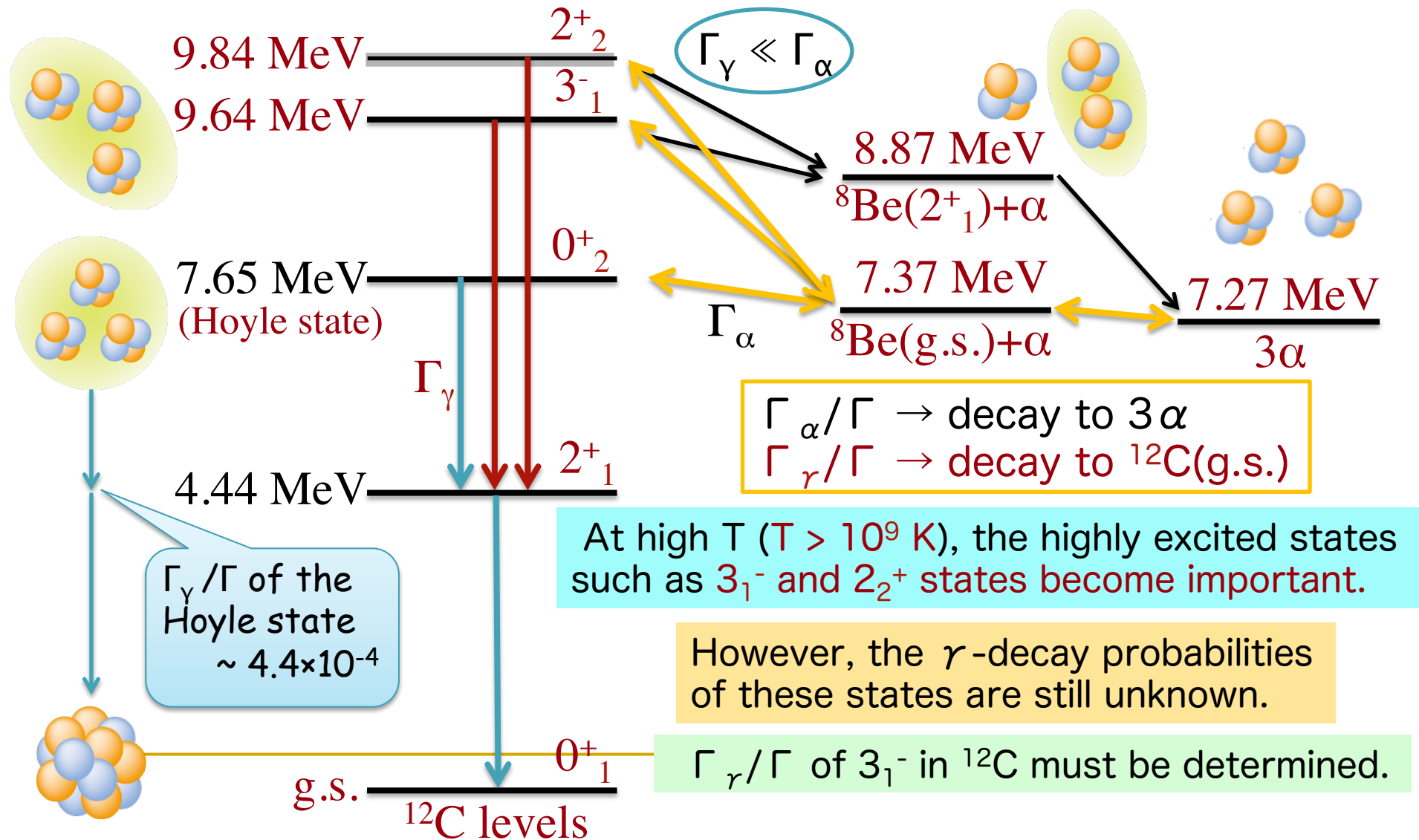
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For RCNP E404 Collaboration

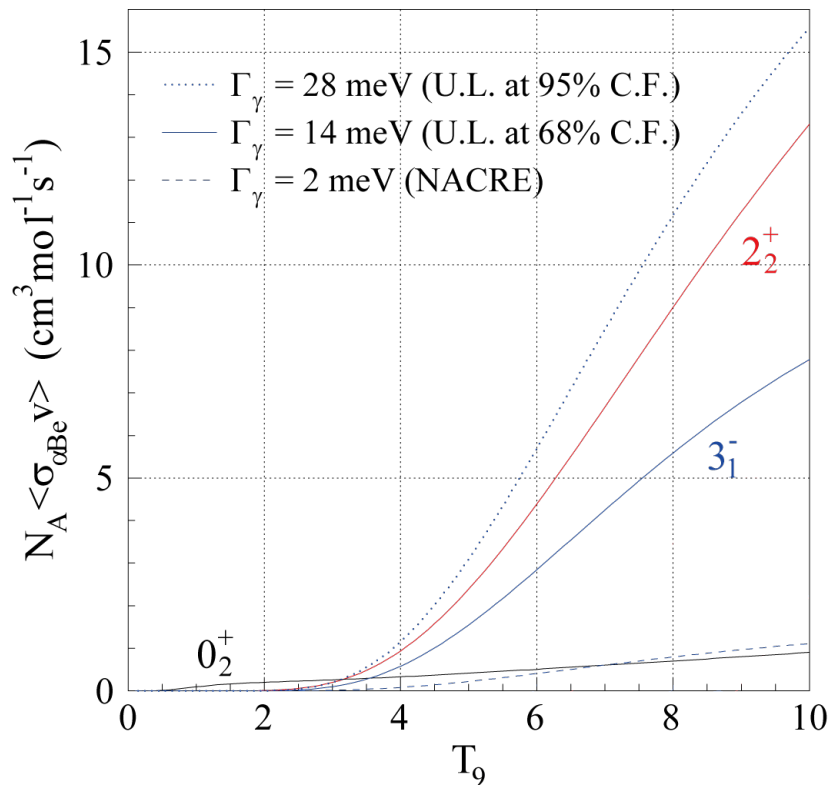
Search for rare γ -decay modes in ^{12}C

The triple α reaction plays a crucial role in the nucleosynthesis.



Triple alpha reaction rate

First star is massive and temperature reaches $T_9 \sim 5$.

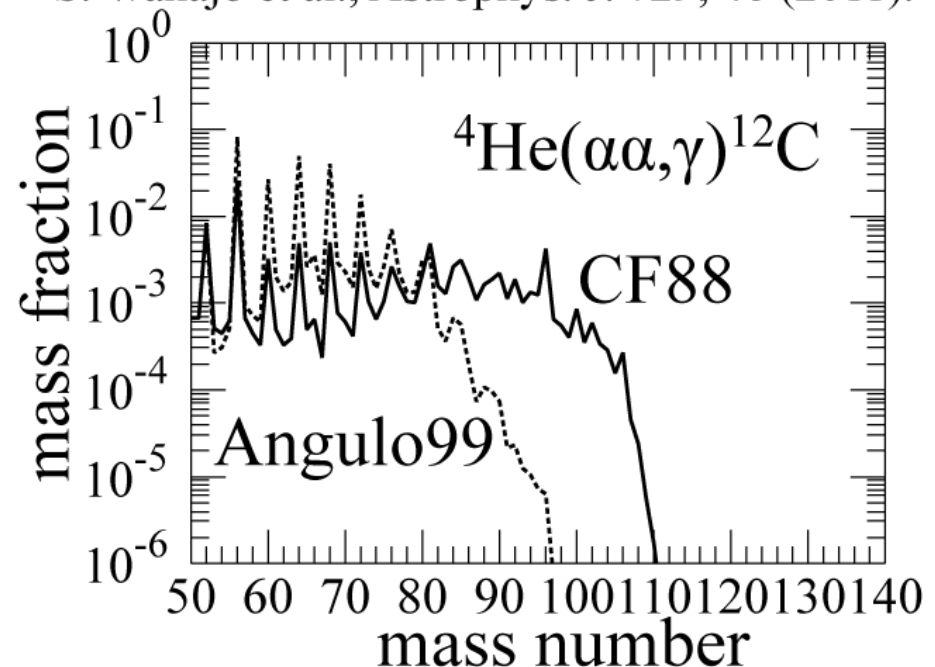


Large Impact on Heavy element abundance by νp process

Angulo99: Include 3_1^- and 2_2^+

CF88: 0_2^+ only

S. Wanajo et al., *Astrophys. J.* **729**, 46 (2011).



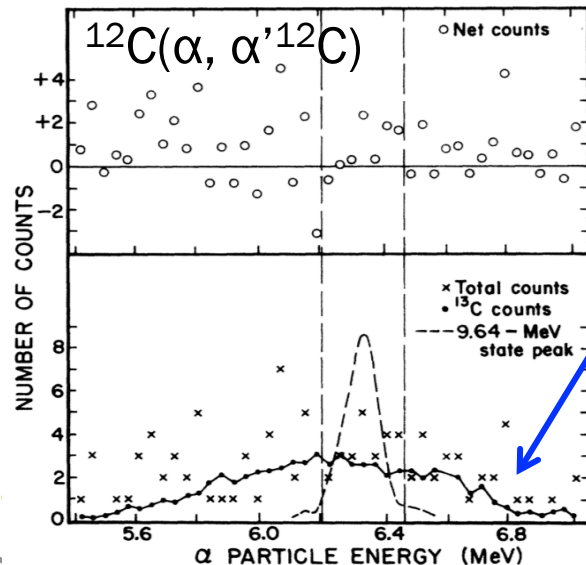
γ -decay probability of the 3_1^- state

Difficult to measure the Γ_γ/Γ of the 3_1^- state because it is very small.

3_1^- in ^{12}C	Total width Γ	γ -decay width Γ_γ	γ -decay probability Γ_γ/Γ
Lower limit	34(5) keV	0.31(4) meV	9.1×10^{-9}
Upper limit		14 meV (1 σ C. L.)	4.1×10^{-7}

Direct γ -decay to the g. s. taken from (e,e')

Previous experiment

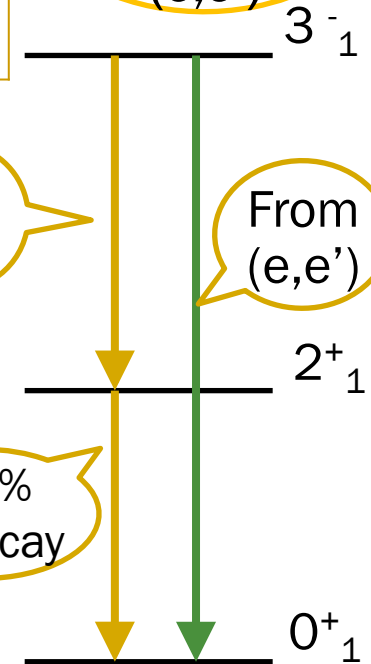


Difficult to measure!!

Background due to ^{13}C contaminants

Use ^{12}C beam not ^{12}C Target!

No ^{13}C contaminants in ^{12}C beam!!



Experimental procedure

Using the inverse kinematic reaction $H(^{12}\text{C}, ^{12}\text{C} p)$, recoil protons and scattered ^{12}C will be measured simultaneously instead of γ -rays.

γ -decay probability Γ_γ / Γ

$$\frac{\Gamma_\gamma}{\Gamma} = \frac{\text{Number of } \gamma\text{-decay events}}{\text{Number of all excited events}}$$

Number of all excited events

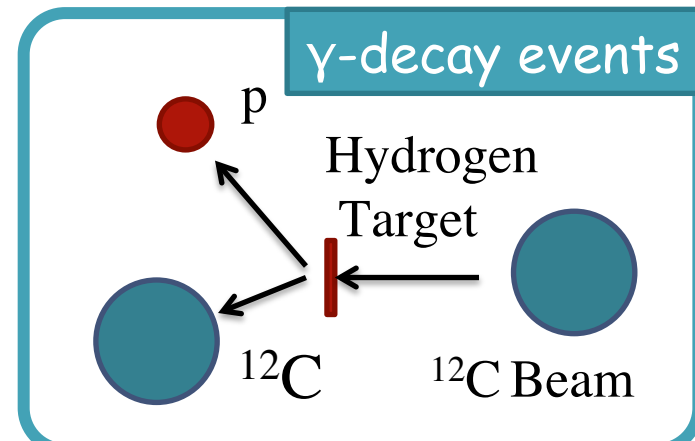
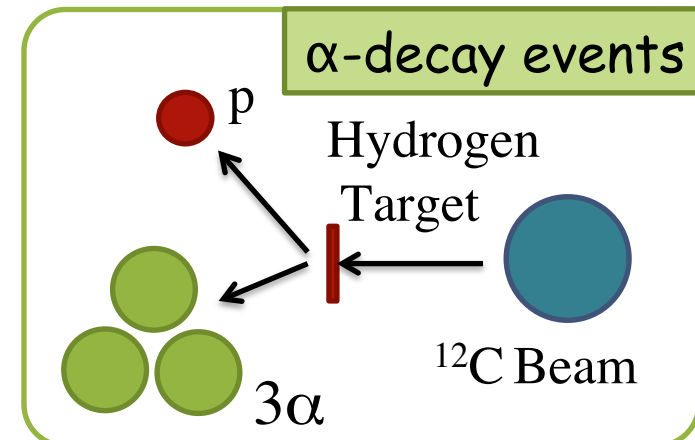
E_x in ^{12}C is determined from the energy and angle of the recoiled proton.

Number of γ -decay events

The scattered ^{12}C should be detected in coincidence with the recoiled proton.

- Thin solid hydrogen target.
- Recoil proton detector.

All excited events



Experimental Setup

The experiment was performed at the cyclotron facility in RCNP.

Recoil proton detector

Particle-identified by Gion (Si+GAGG telescope).

Recoiled angle...The double-sided Si strip detector.

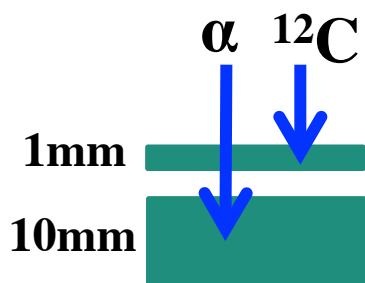
Energy...The GAGG crystal.

→ E_x of the scattered ^{12}C

Count the number of the all excited events

A solid H target is bombarded with a ^{12}C beam.

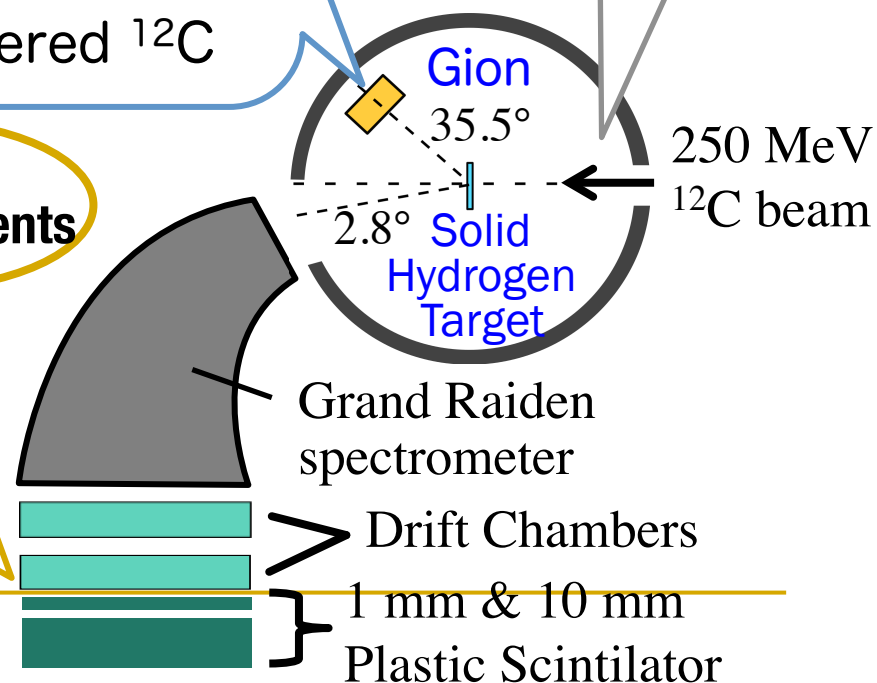
Scattered ^{12}C detector



Anti-coin between 2 scintillators

→ ^{12}C trigger

Select γ -decay events

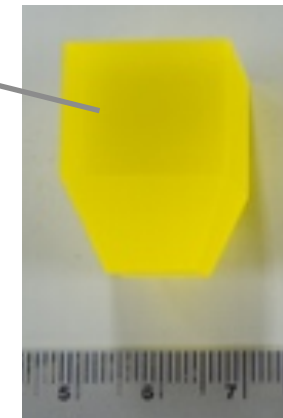
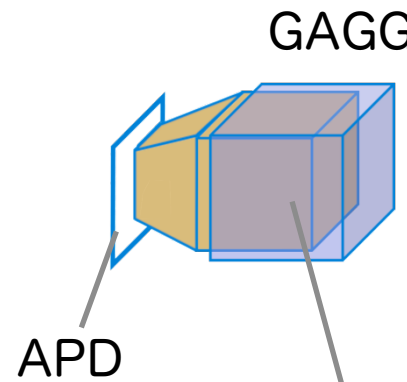
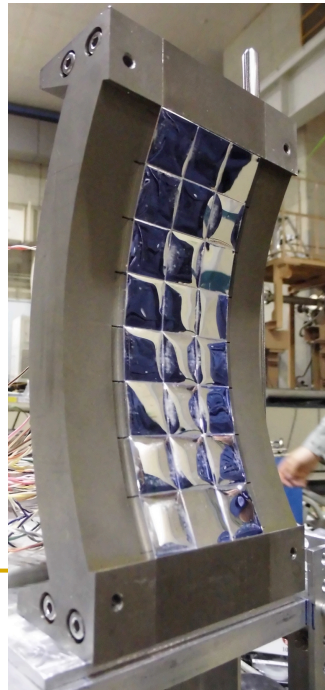
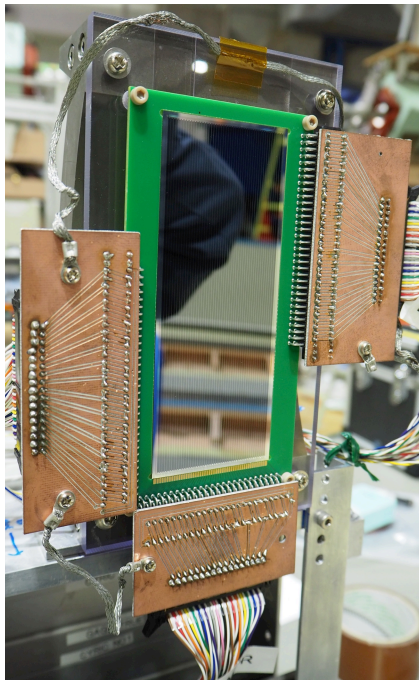
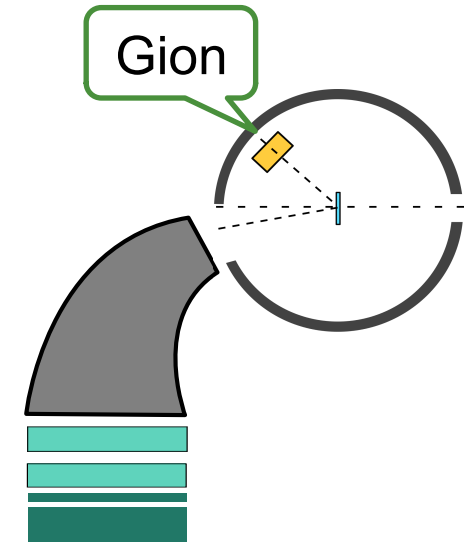


Gion Recoil proton counter

Gion = GAGG based light ion counter telescope

■ GAGG $Gd_3Al_2Ga_3O_{12}$.

	Density (g/cm ³)	$\Delta E/E$ (FWHM) @662 keV	Decay time (ns)	Light output (photon/ MeV)
CsI(Tl)	4.51	~6%	~1000	~56000
GAGG(Ce)	6.63	5-6%	88	65000



Wrapped by 65- μ m ESR film (3M)

- ✓ Double sided Si strip (16 x 32) detector
- ✓ 18 x 18 x 18 mm³ GAGG x 24 個

Solid Hydrogen Target (SHT)

Develop SHT to suppress background.

Target	H/Contaminant
SHT*	3.913
CH ₂	0.167

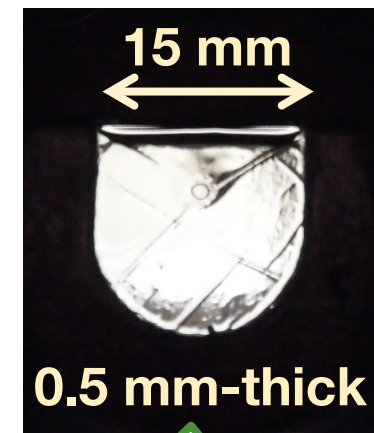
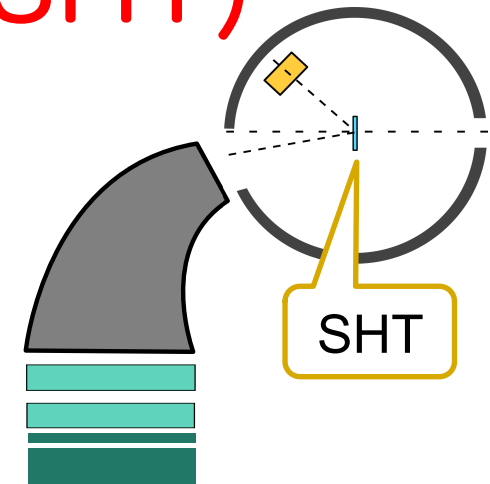
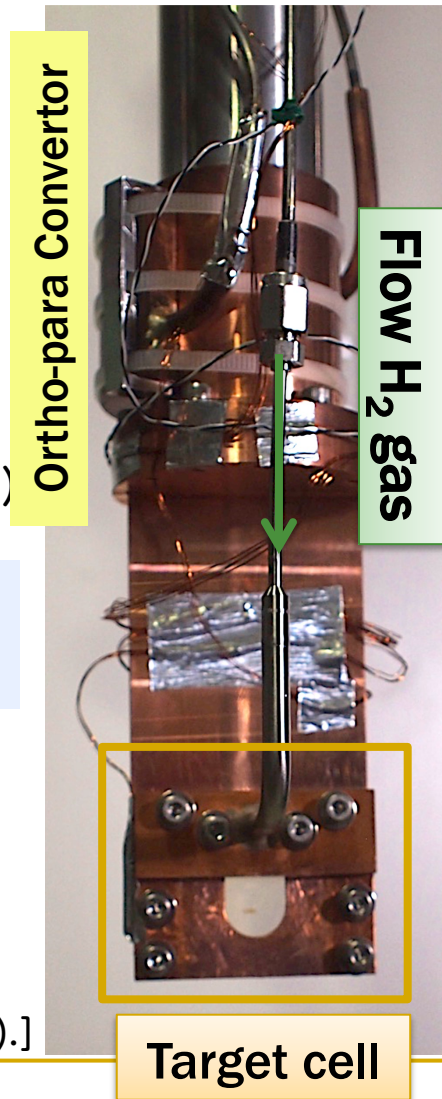
×23.4

* Include gas-sealing Aramid film (4 μm x 2)

Thickness should be thinner than 0.5 mm for $\Delta E_x < 250$ keV.

Ortho-para convertor
→ Enhance thermal conductivity of the solid hydrogen.

[Y. Matsuda, M. Tsumura, T. Kawabata *et.al.*,
J. Radioanal. Nucl. Chem. 305, 897--901 (2015).]

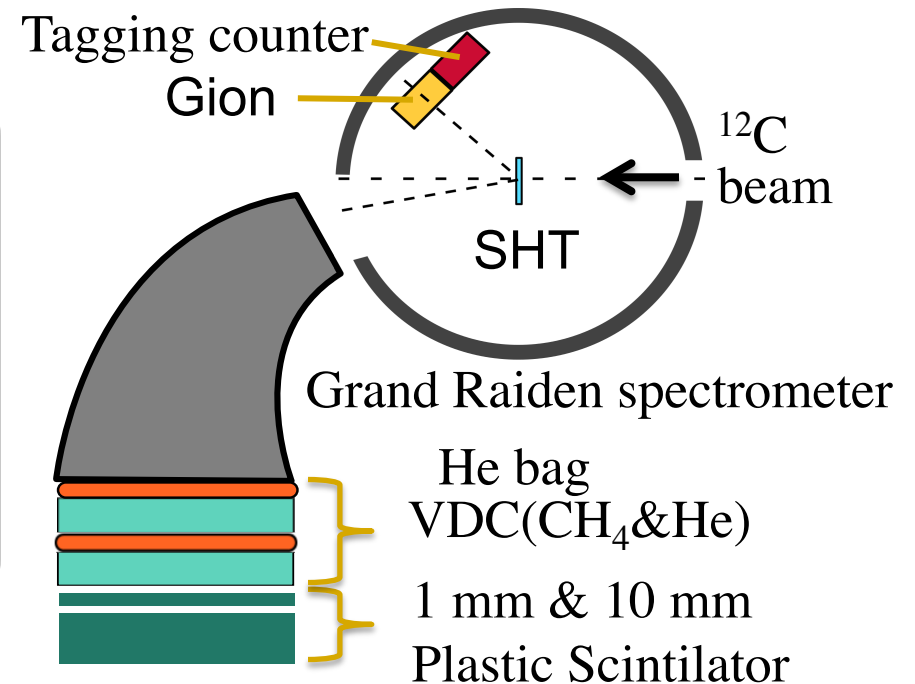
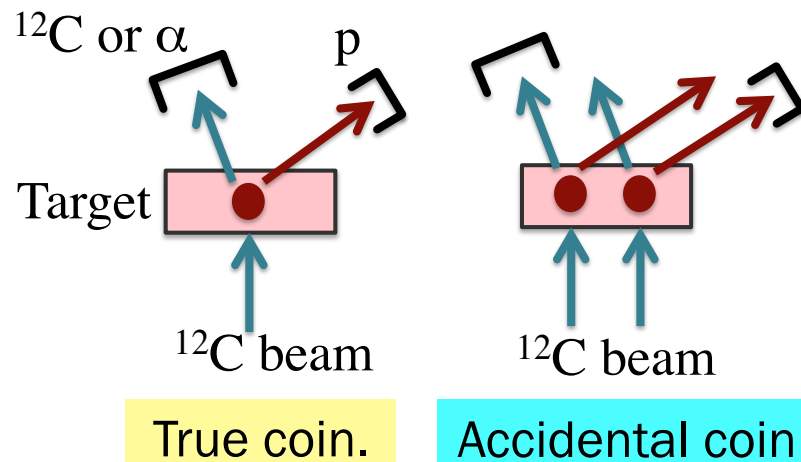


Thin!!

Improvement of the S/N

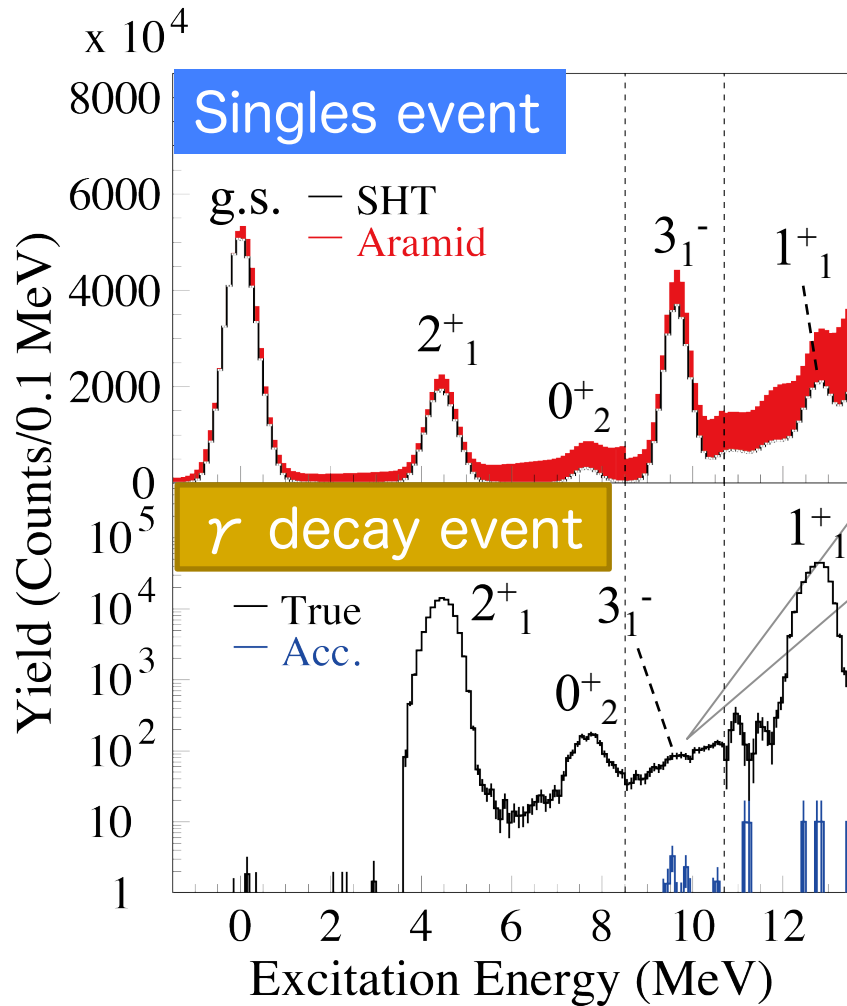
Accidental coincidence events cause serious background.

What's accidental coin. event?

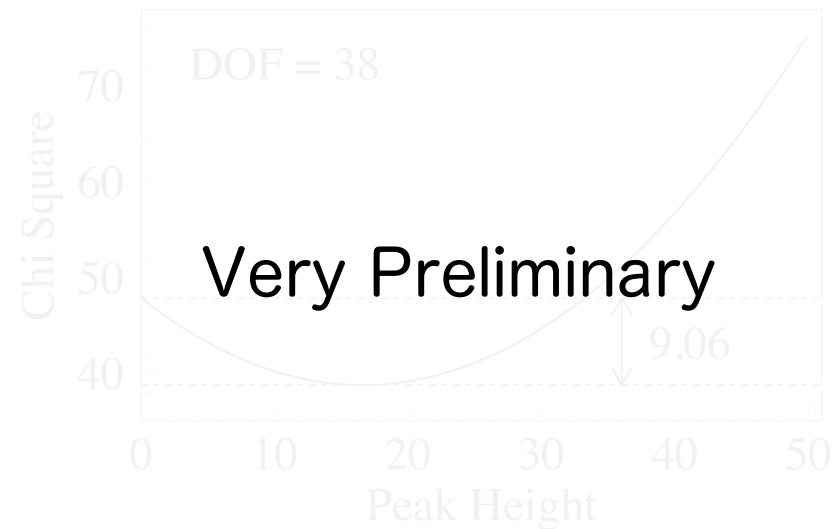
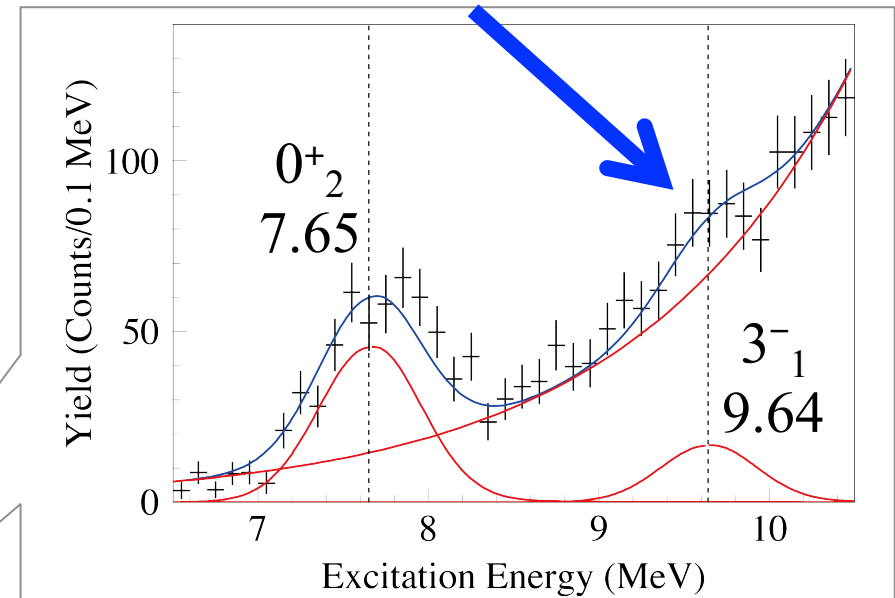


- Tagging counter (Gion)
 - …To remove **accidental coincidence events**.
- Data reduction gate
 - Angular correlation between p and ^{12}C .
 - Energy correlation between p and ^{12}C .

Results



γ -decay from 3^-_1 was observed !



Gamma Decay Probability

γ -decay probability is given by

$$\frac{\Gamma_\gamma}{\Gamma} = \frac{\# \text{ of } \gamma \text{ decay events}}{\# \text{ of singles events}} \times \frac{1}{\text{geo. eff.}}$$

Geometrical efficiency should be estimated by MC calculation.

	0^+_{2}	1^+_{1}	3^-_{1}
Geo. Efficiency	0.117(2)	0.186(9)	0.229(3)
Γ_γ/Γ Previous	$4.4(5)\times 10^{-4}$	$2.21(7)\times 10^{-2}$	Very Preliminary
Γ_γ/Γ Present	$4.0(5)\times 10^{-4}$	$2.5(6)\times 10^{-2}$	$2.1(6)\times 10^{-2}$

Present result is very preliminary, but consistent with the previous result on the 0^+_{2} and 1^+_{1} states.

Final result will be reported elsewhere soon.

Summary

- Measurement of the γ -decay probability of the 3_1^- state in ^{12}C .
 - Importance for the 3α reaction.
 - New detection scheme using the inverse kinematic reaction $\text{H}(^{12}\text{C}, ^{12}\text{C} p)$ without γ -ray measurement.
 - γ -decay events are successfully identified.
 - γ -decay events from the 3_1^- state were observed.
 - Final results will be reported elsewhere soon.
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