RCNP研究会
「核子・ハイペロン多体系におけるクラスター現象」 2013.07.27

^{12}C原子核における3_1^-状態の稀γ崩壊モード探索実験

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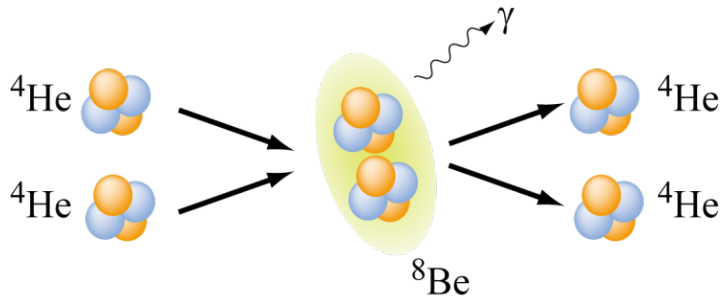
Nucleosynthesis & Triple α reaction

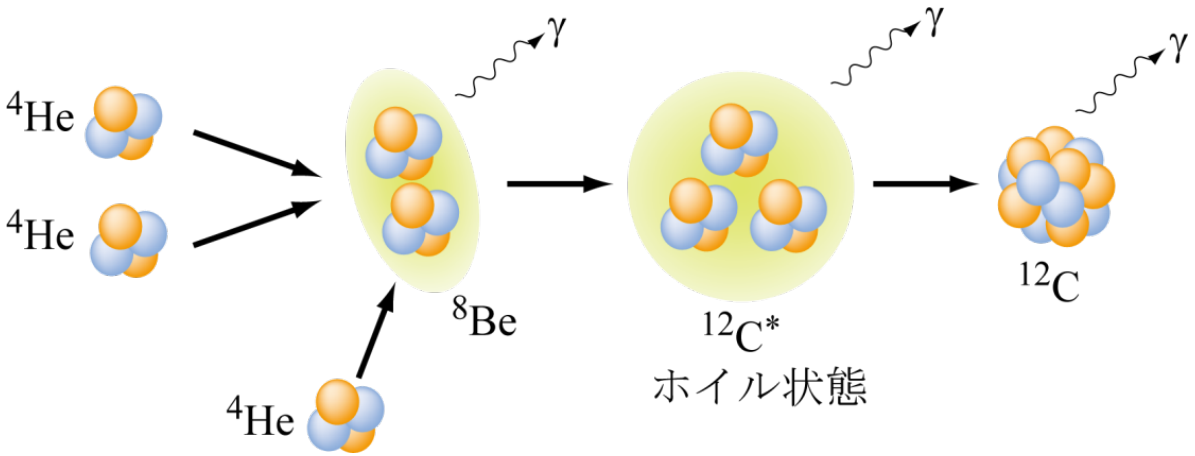
Stars are factory of nucleus.

- p-p chain : ^{4}He production
- A=5,8 wall are bottle neck
- triple-alpha : ^{12}C production

Fred Hoyle proposed "3α-like" resonance excited state in ^{12}C.

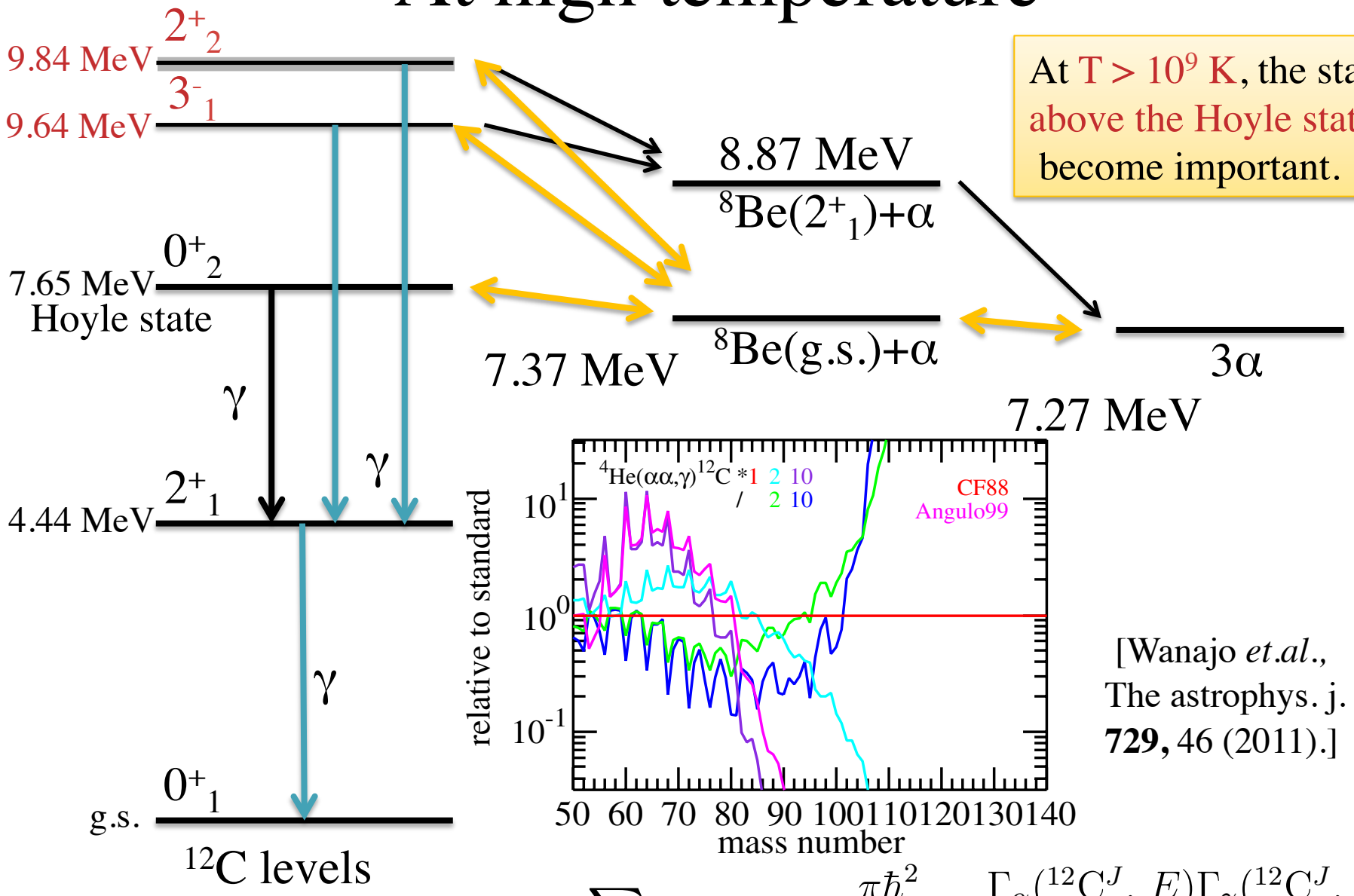
Hoyle state
0_2^+ (7.65 MeV)





Triple a reaction is important to synthesis heavier nuclei.

At high temperature

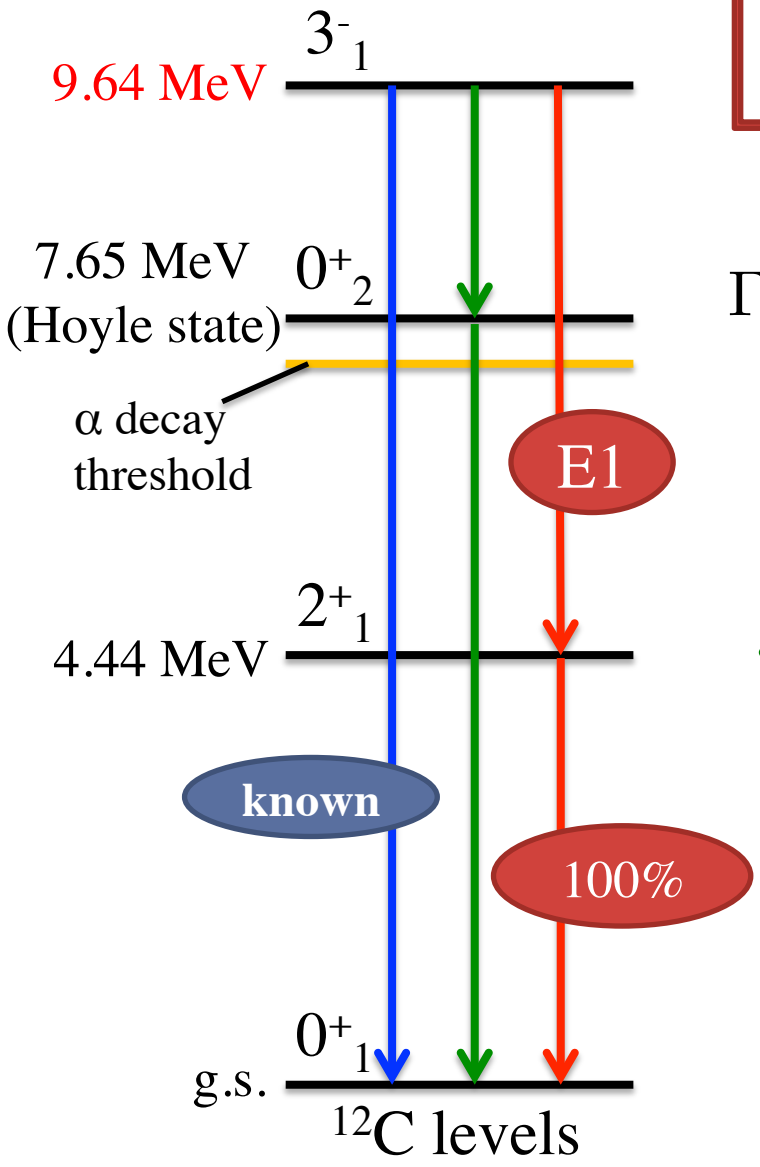


At $T > 10^9$ K, the states above the Hoyle state become important.

[Wanajo *et.al.*, The astrophys. j. **729,** 46 (2011).]

$$\sigma_{\alpha^8\mathrm{Be}}(E) = \sum_{J=0,\,2,\,3} (2J+1)\frac{\pi\hbar^2}{2\mu_{\alpha^8\mathrm{Be}}E}\frac{\Gamma_\alpha(^{12}\mathrm{C}^J,\,E)\Gamma_\gamma(^{12}\mathrm{C}^J,\,E)}{(E-E_r^J)^2+\frac{1}{4}\Gamma(^{12}\mathrm{C}^J,\,E)^2}$$

γ transition of 3_1^- state



Total decay width

$$\Gamma = \Gamma_\alpha + \Gamma_\gamma = 34 \text{ keV} \qquad \Gamma_\alpha \gg \Gamma_\gamma$$

Gamma decay width is still unknown.

$$\Gamma_\gamma = \Gamma_{3_1^- \to \text{g.s.}} + \Gamma_{3_1^- \to 0_2^+ \to \text{g.s.}} + \Gamma_{3_1^- \to 2_1^+ \to \text{g.s.}}$$

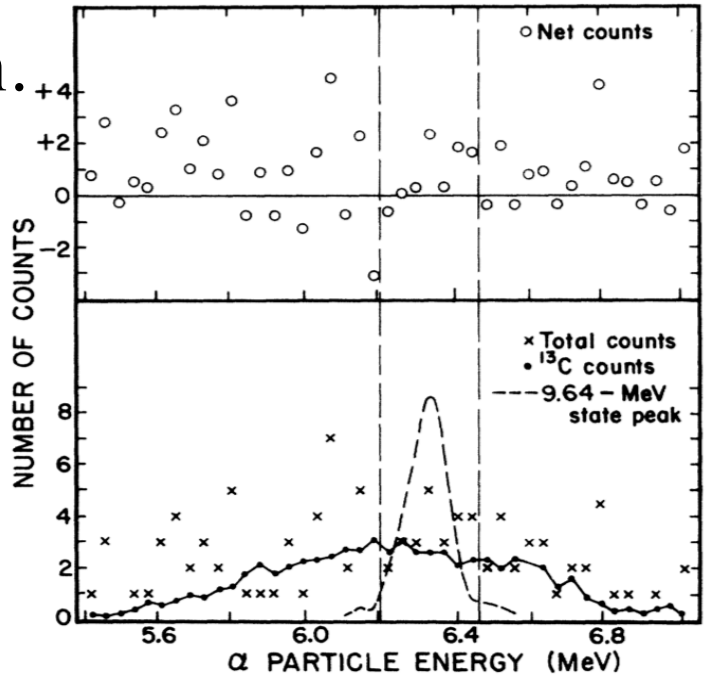
- Direct decay
  Measured by electron scattering.
  = 0.31±0.04 meV ← lower limit
- Cascade decay via the Hoyle state
  Contributes little to the total gamma width.
- Cascade decay via the 2^+_1 state might be a main decay branch.

Typical width of isospin forbidden E1 transition ～ 10 meV

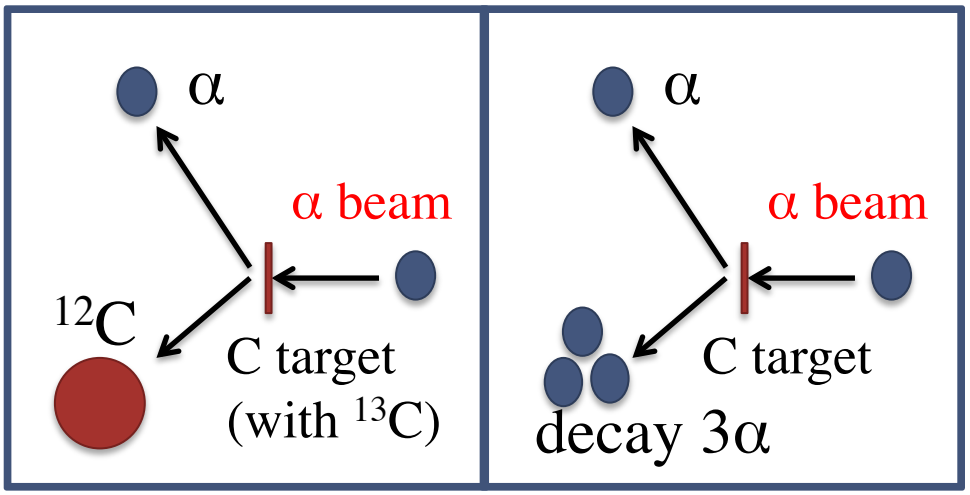
Previous Experiment

Measurement by $^{12}C(\alpha, \alpha' {}^{12}C)$ reaction.

[D. Camberlin *et.al.*, Phys.Rev.C **10,** 2 (1974).]



Only to get the upper limit due to contamination in ^{12}C enriched target.



γ decay α decay

Upper limit

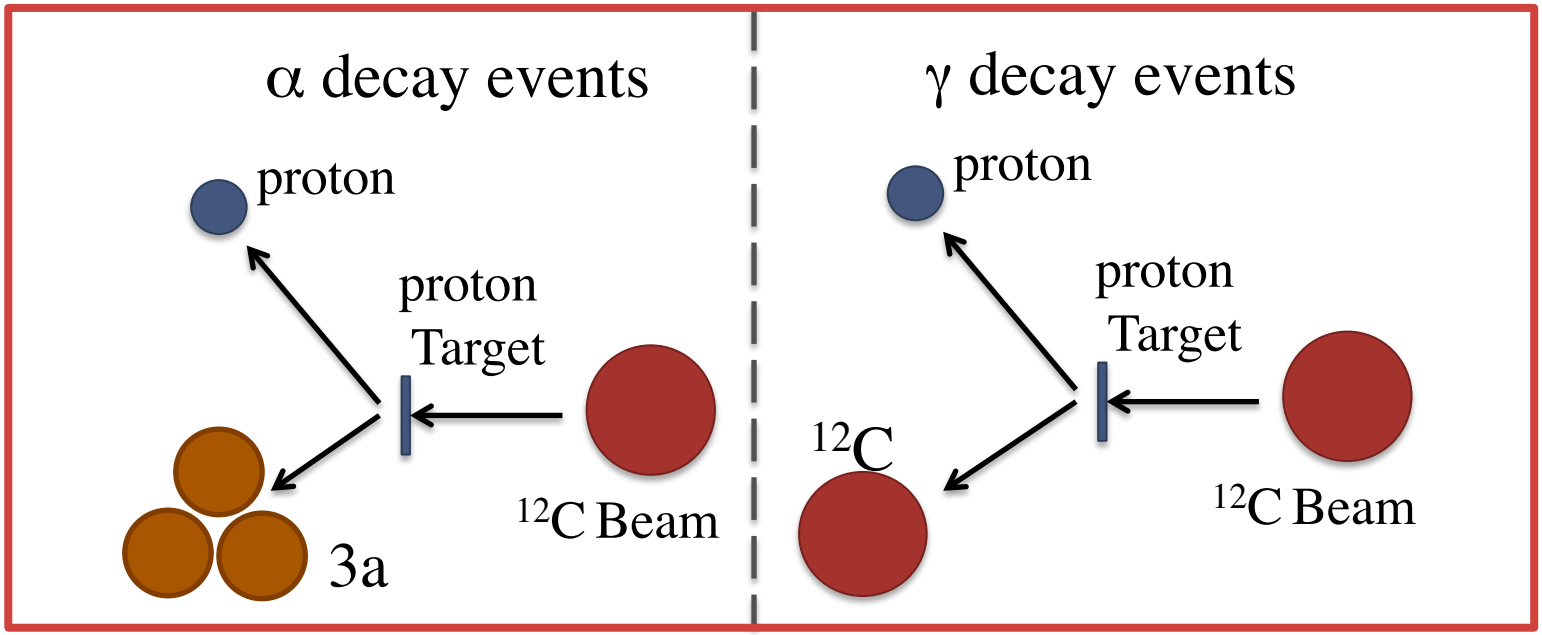
68% CL : 4.1×10^{-7} (14 meV)
95% CL : 8.2×10^{-7} (28 meV)

^{13}C causes serious backgroundcontamination in ^{12}C enriched target.

Our test measurement

To remove background events from ^{13}C,
we measured the inverse kinematic $CH_2(^{12}C, ^{12}C^*p)$ reaction.

Excited events



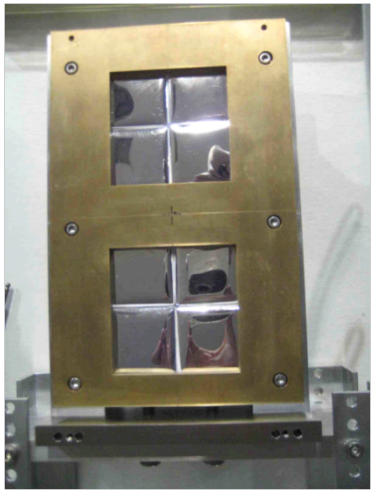
Target : $^{nat}CH_2$(Background run → ^{nat}C) measured in March 2012 in RCNP.
Recoiled proton : Si+CsI telescope
Scattered ^{12}C : Grand Raiden spectrometer & Plastic Scintillator

branching ratio $\frac{\Gamma_\gamma}{\Gamma} = \frac{\gamma \text{ decay events}}{\text{excited events}}$

Detector & Setup

- **$^{nat}CH_2(^{12}C, ^{12}C^*p)$**
- **Beam Energy: 250MeV**
- **Target: cold CH_2 2mg/cm²**

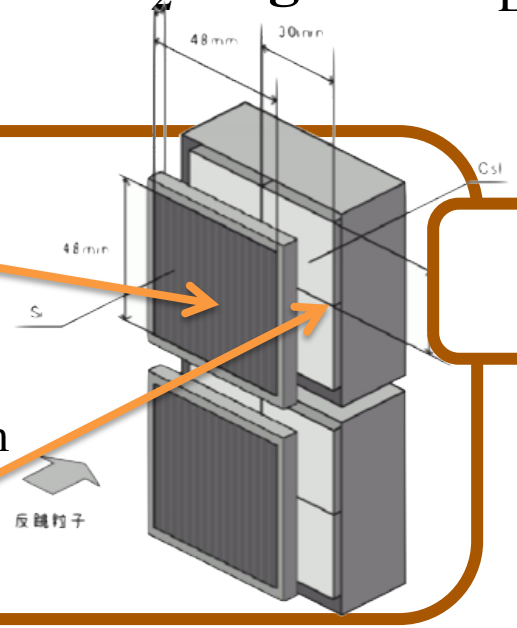
CsI & ESR film



brass collimator

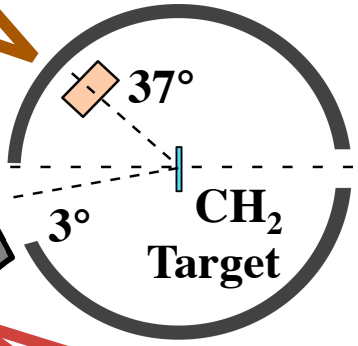
Si: 3mm×48mm ×16strips×2 325um thick

CsI: 30mm×30mm ×4blocks×2

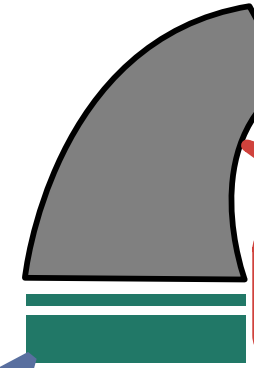


Si + CsI (cover 31.3°～42.7°)

→ **select proton**

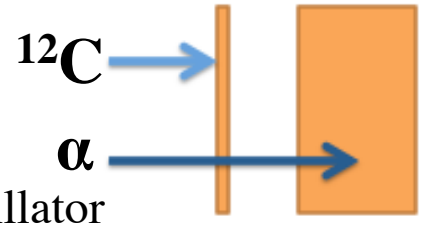


^{12}C Beam 250MeV



Grand Raiden Spectrometer (cover 2.5°～3.8°)

Only a can penetrate 1mm-Scintillator → trigger

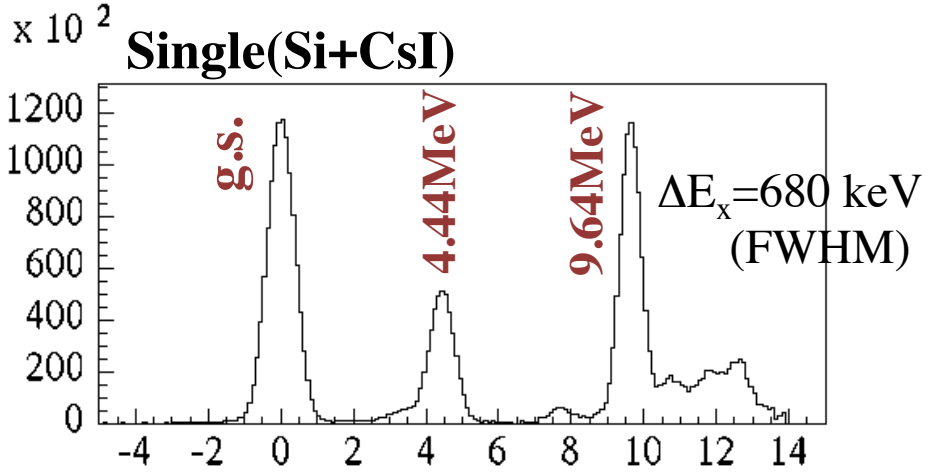


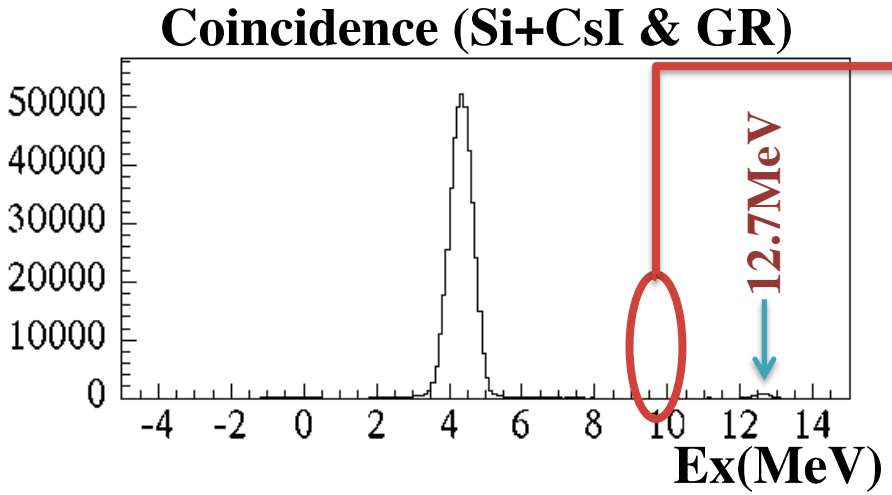
Plastic Scintillators 1mm & 10mm

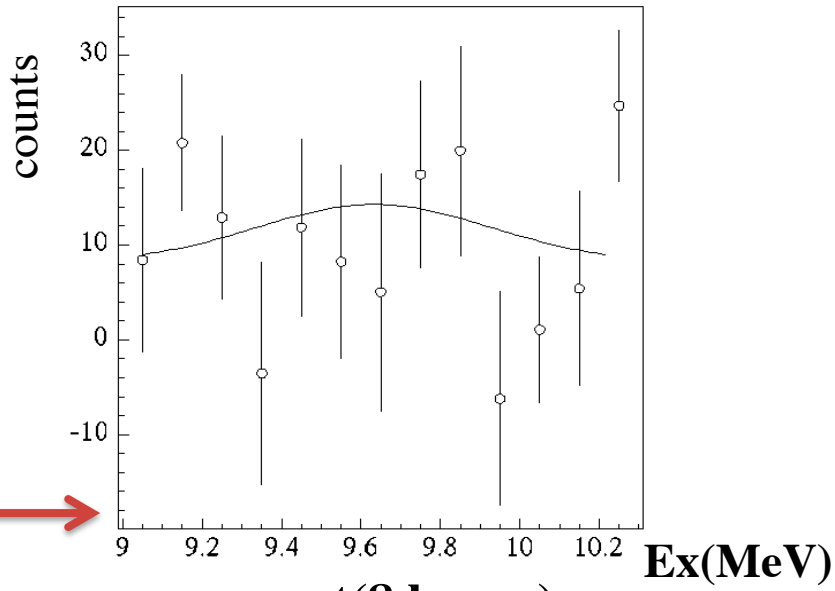
↓

→ **select γ decay events**

results of test measurement







Our measurement(8 hours)

Upper limit of branching ratio

1σ-CL	**3.87×10^{-6} (132meV)**
2σ-CL	**1.27×10^{-5} (432meV)**

cf.) Previous experiment

1σ-CL	4.12×10^{-7}(14meV)
2σ-CL	8.24×10^{-7}(28meV)

[D. Camberlin *et.al.*, Phys.Rev.C **10,** 2 (1974).]

branching ratio

Γ =34keV

$$\frac{\Gamma_\gamma}{\Gamma} = \frac{\gamma \text{ decay events}}{\text{excited events}}$$

Upgraded experiment

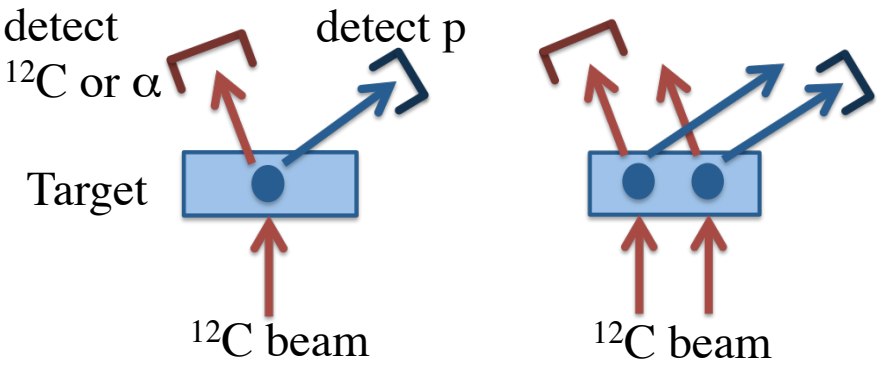
We need to accumulate more statistics and to improve the signal-to-noise ratio.

To accumulate more statistics

- Beam time 8 hours -> 10 days
- Large Si strip detector 1.7 times

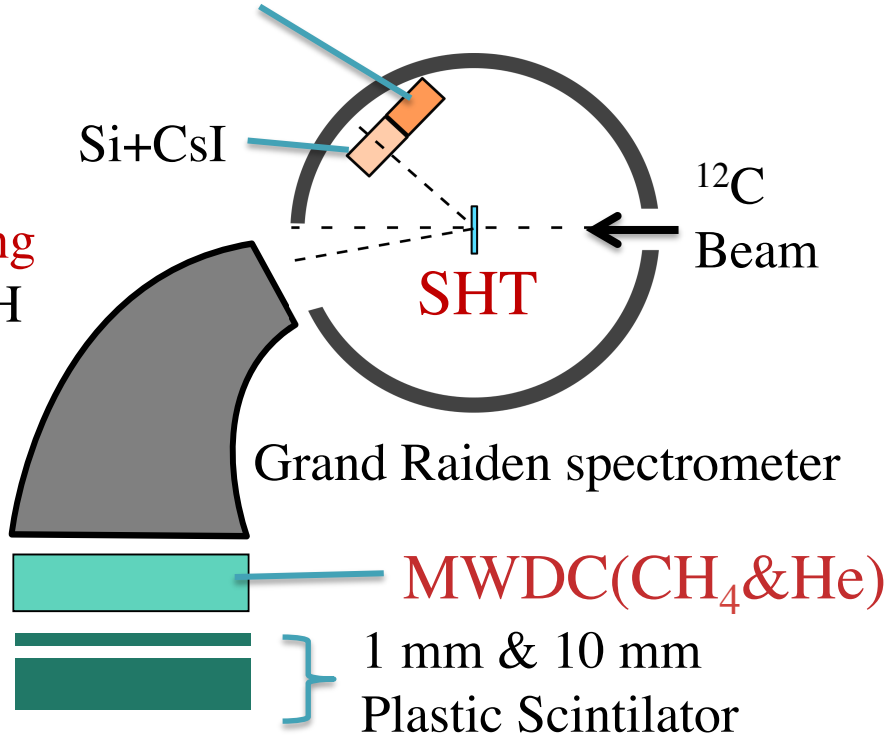
To improve S/N

- Target: CH2 -> Solid Hydrogen Target
  … decrease background events from C
- Introduce Si+CsI detector for event tagging
  … remove accidental coin events from H
- Track ^{12}C with low-material MWDC
  …select using scattering angle



True coincidence

Accidental coincidence



Monte Carlo Simulation

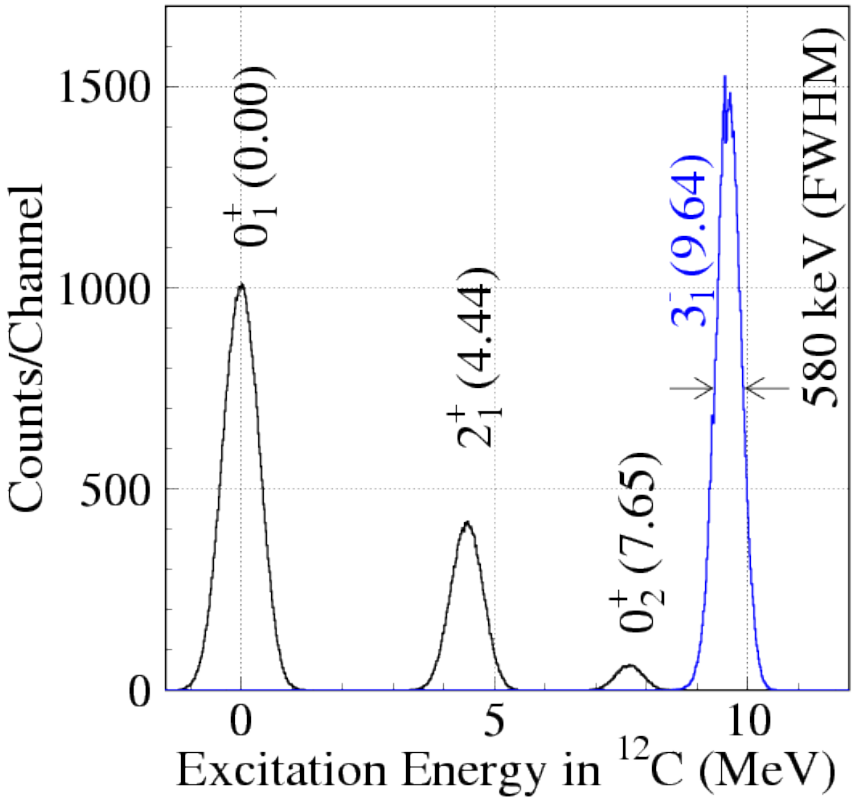
Monte Carlo Simulation was carried out considering experimental condition as below.

Beam
Energy: 250 MeV(20.8 MeV/u)
Intensity: 0.1pnA
Energy spread: 0.2 MeV (sigma)
Angular spread: 2 mr (sigma, in-plane)
Spot size: 0.5 mm (sigma)

Target : Solid Hydrogen Target 0.5 mm
(0.0763 g/cm^2)

Si+CsI detector
Angle: 35.5°
Distance from target: 125 mm
Energy resolution: 0.3 MeV (sigma)

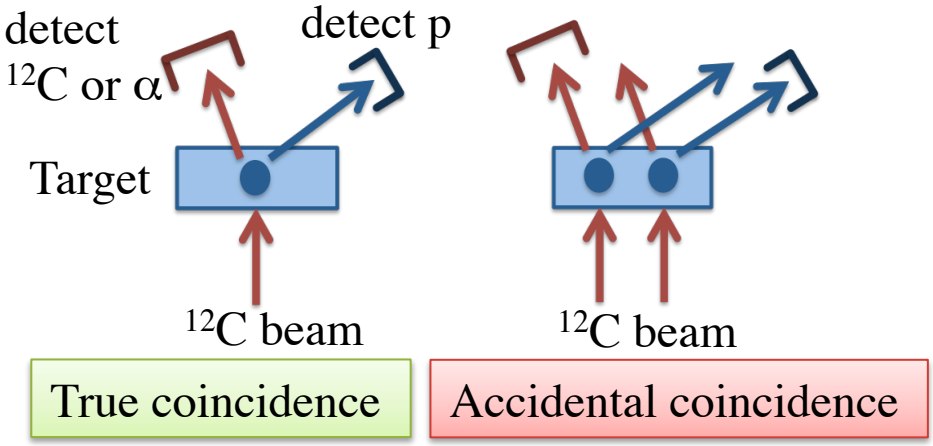
Grand Raiden spectrometer
Angle: 2.8°
Acceptance: ±14 mr (Horizontal)
±35 mr (Vertical)
Δp/p = ±2%

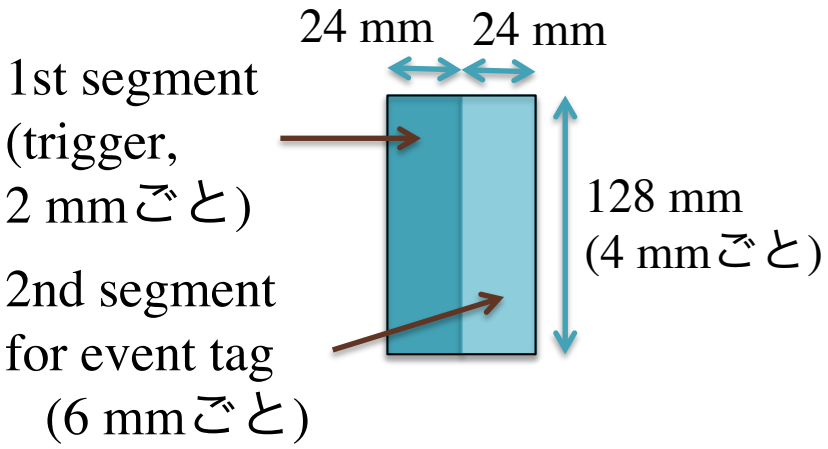


Focal plane detector
Intrinsic angular resolution: 2 mr (sigma, Horizontal)
4 mr (sigma, Vertical)
Detector thickness: 60 mg/cm^2

Accidental coin events from H(^{12}C,^{12}C*)

Accidental coincidence events from ^{1}H(^{12}C, ^{12}C*) , especially from ^{1}H(^{12}C, ^{12}C(4.44 MeV)), is serious.





Accidental coincidence rate for each states are estimated as below:

J^{π}	use only 1st segment	1st and 2nd segment
0_1^+(g.s.)	1.0×10^{-3} cps	1.0×10^{-4} cps
2_1^+(4.44 MeV)	5.6×10^{-1} cps	2.7×10^{-3} cps
0_2^+(7.65 MeV)	4.4×10^{-5} cps	8.8×10^{-7} cps

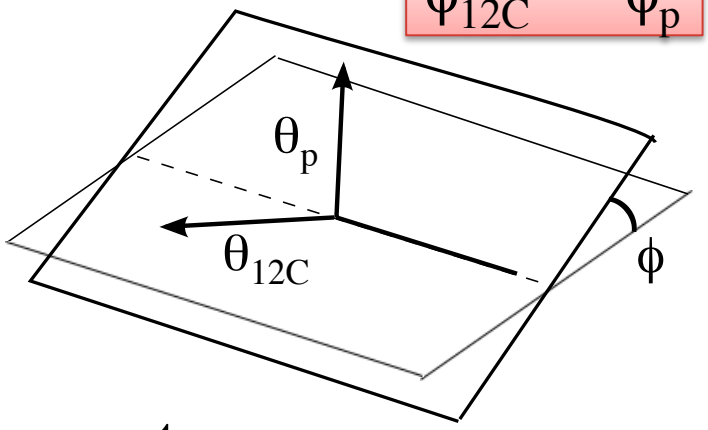
Accidental coin events from H(^{12}C, ^{12}C*) can be reduced by a factor of 190 .

Background elimination gate

ϕ gate

using scattering azimuthal angle

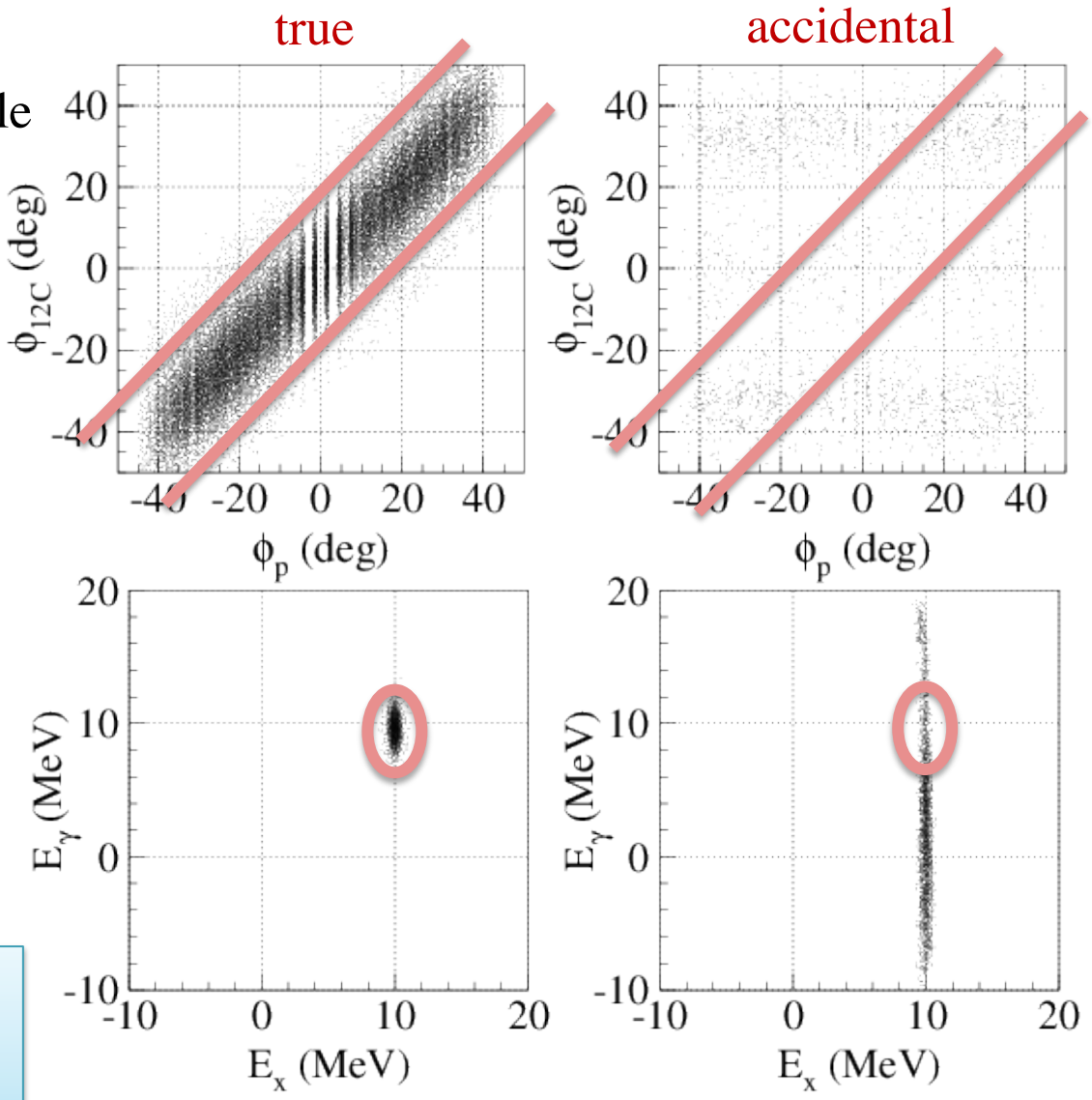
$\phi_{12C} \sim \phi_p$



γ gate

$E_x \sim E_\gamma$
$= E_{beam} - E_p - E_{12C}$

The ϕ and γ gates suppress the accidental coincidence events by a factor of 35.



Yield estimation

Numbers of the coincidence events between proton and ^{12}C was estimated as below for 10 days beam time.

J^{π}	Γ	Γ_{γ}	Γ_{γ}/Γ	ε_{coin}	Number of events
0^{+}_{1}				0.0	
2^{+}_{1}	10.8 (6) meV	10.8 (6) meV	1	0.021	6.0×10^{7}
0^{+}_{2}	8.3 (10) eV	3.7 (5) meV	$4.4\ (5) \times 10^{-4}$	0.535	8.2×10^{4}
3^{-}_{1}	34 (5) keV	< 14 meV	$< 4.1 \times 10^{-7}$	0.753	$< 2.4 \times 10^{3}$
		>0.31±0.04meV	$>9.1\times10^{-9}$		>54

Number of accidental coin events:

Using Si+CsI for event tag, SHT, ϕ and γ gates

	test setup	upgraded setup
Background from H(12C,12C*)	450 k	67
Background from X(12C, 12C*)	150 k	104

Even if the γ decay width of 3_1^- state is 0.31 meV ($\Gamma_{\gamma}/\Gamma \sim 10^{-8}$, lower limit) , γ decay width can be determined.

Summary

- Purpose:
  measure the rare γ decay width for $^{12}C(3_1^- \rightarrow g.s.)$
- Our test measurement indicated the effectiveness of using inverse kinematic reaction $^{1}H(^{12}C, ^{12}C^*p)$.
- Detail simulation for upgraded experiment was done.
  - Our upgraded experiment has sensitivity of 10^{-8} about Γ_γ/Γ .
- 2nd test measurement is scheduled in this October.

Thank you for your attention!!