Measurement of inelastic alpha scattering on ^{14}O

RIKEN

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Studies at RIKEN

- Compressional modes in unstable nuclei
- Year 2000, $^{14}O(\alpha,\alpha')$
  - This work, Rikkyo Univ., Tokyo Univ., RIKEN
- Recently, ISGMR by (p,p')
  - Measure recoil proton
  - Tohoku Univ.
- Future, at new facility RIBF
  - ISGMR/GDR for medium heavier n-rich nuclei
  - EOS

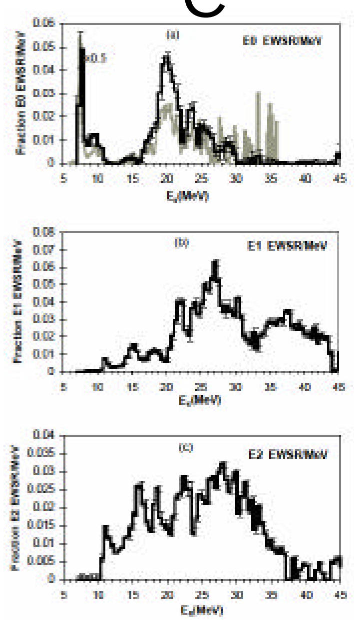
Inelastic α scattering on ^{14}O at 60 *A* MeV

- Experimental methods
  - Inverse kinematics
  - Liquid helium target
  - Invariant-mass method
    - Detector acceptance
    - Multiple decay particles
    - γ ray from decay particles
  - Multipole decomposition analysis
    - DWBA, optical and transition potentials

Isoscalar strengths for light stable nuclei

- $^{12}C(\alpha,\alpha')$ at 60 *A* MeV
  - B. John et. al., Phys. Rev. **C68** (2003) 014305
- $^{16}O(\alpha,\alpha')$ at 60 *A* MeV
  - Y.-W. Lui et. al., Phys. Rev. **C64** (2001) 064308
- Fragmented distribution

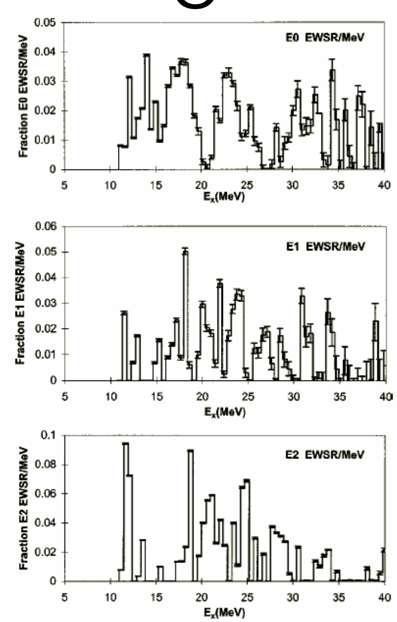
^{12}C ^{16}O



monopole

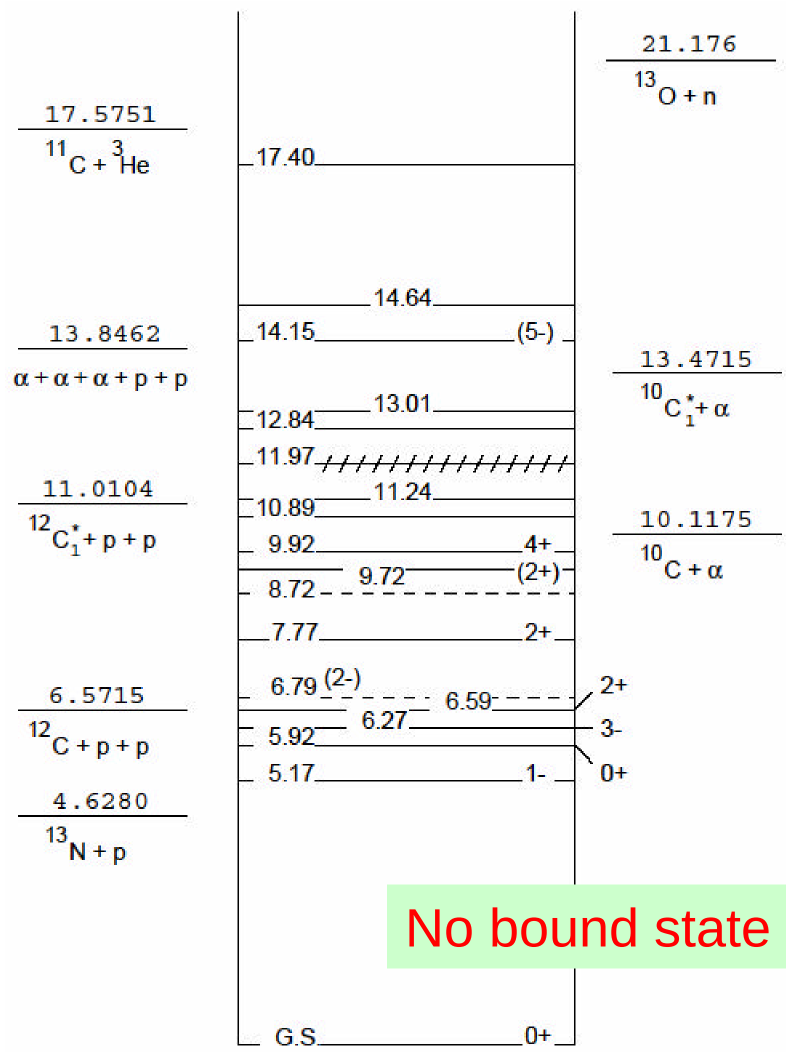
dipole

quadrupole



Light unstable nucleus ^{14}O

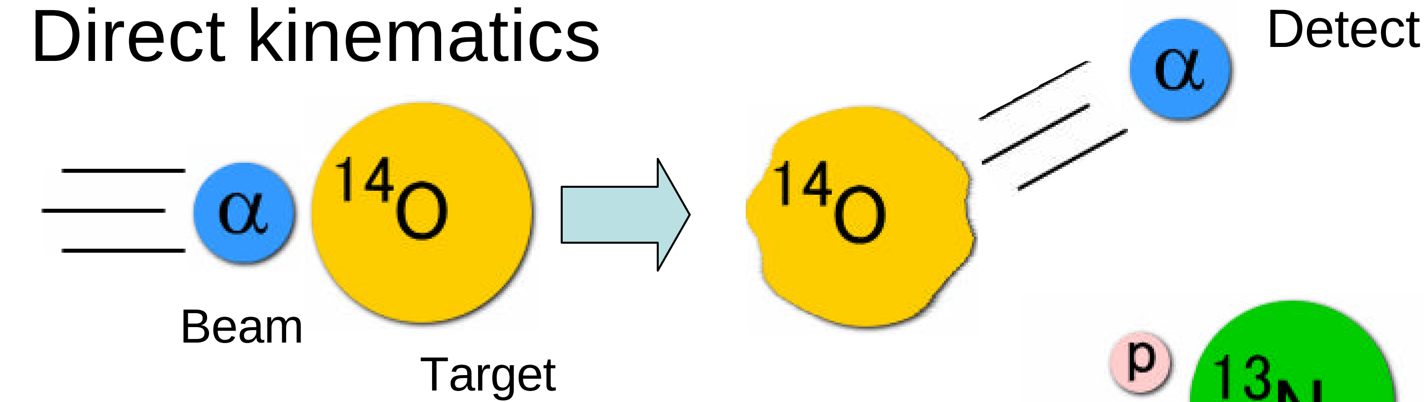
- Z=8, N=6
  - Sphelical
- Measured decay channel
  - $^{13}N + p$ — 4.6 MeV
  - $^{12}C + p + p$ — 6.6 MeV
  - $^{12}C^*_1 + p + p$ — 11.0 MeV
  - $^{10}C + \alpha$ — 10.1 MeV
  - $^{10}C^*_1 + \alpha$ — 13.5 MeV



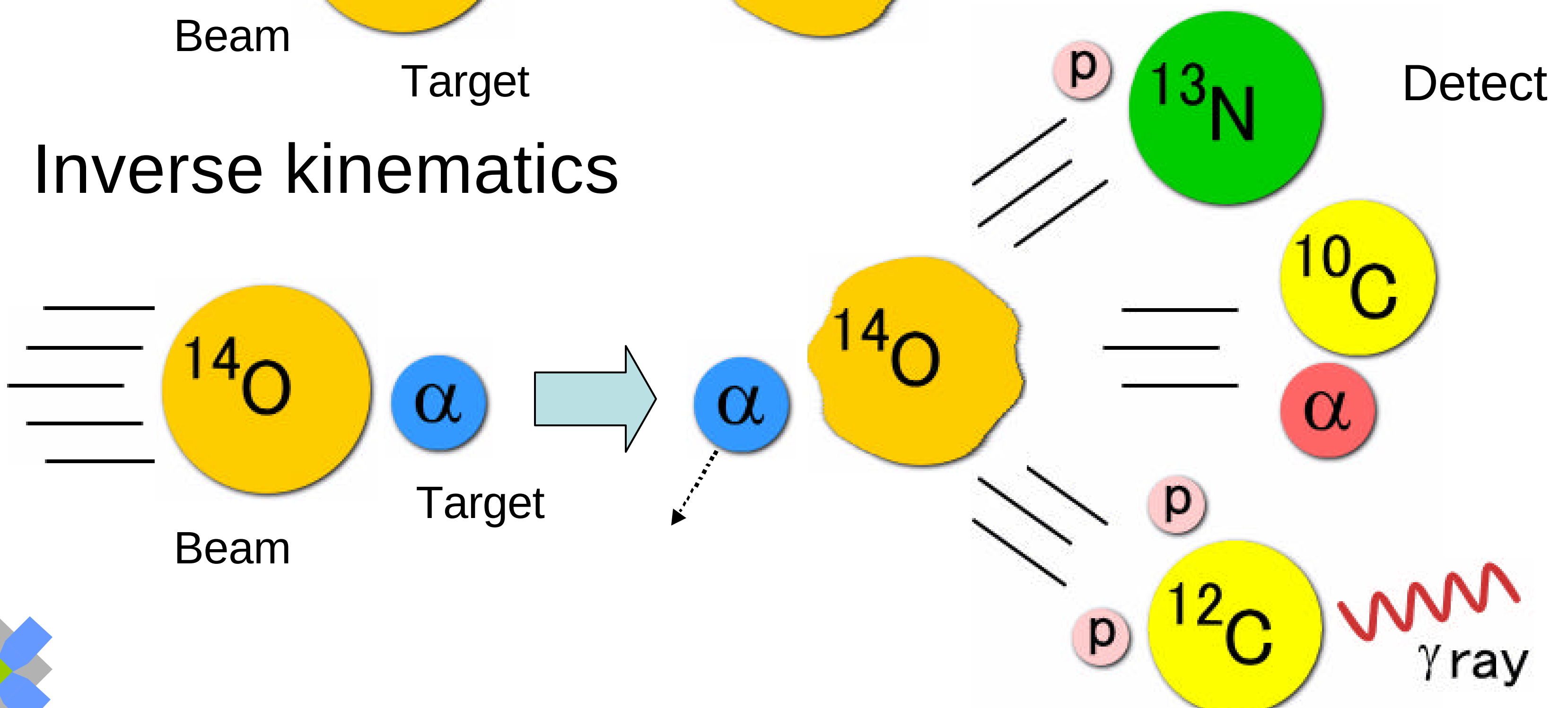
No bound state

Inverse kinematics

- Direct kinematics



- Inverse kinematics



Invariant-mass method

- In order to obtain excitation energy
- E_{decay} is calculated from momentum vectors of decay particles

Decay energy

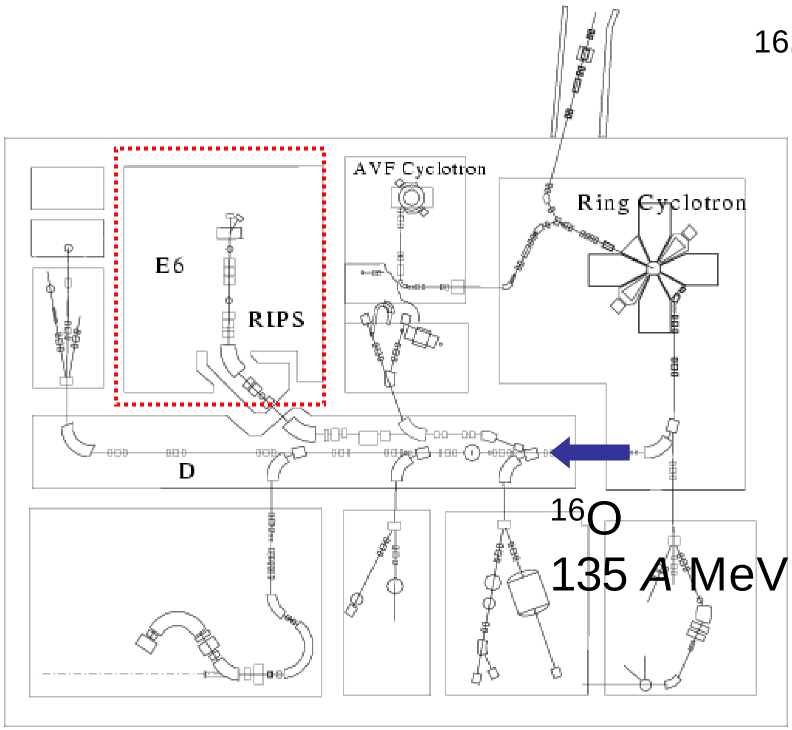
$$E_{decay} = \sqrt{\left\{\sum_i (m_i + T_i)\right\}^2 - \left\{\sum_i \mathbf{p}_i\right\}^2} - \sum_i m_i$$

$$E_x = E_{decay} + E_{threshold}$$

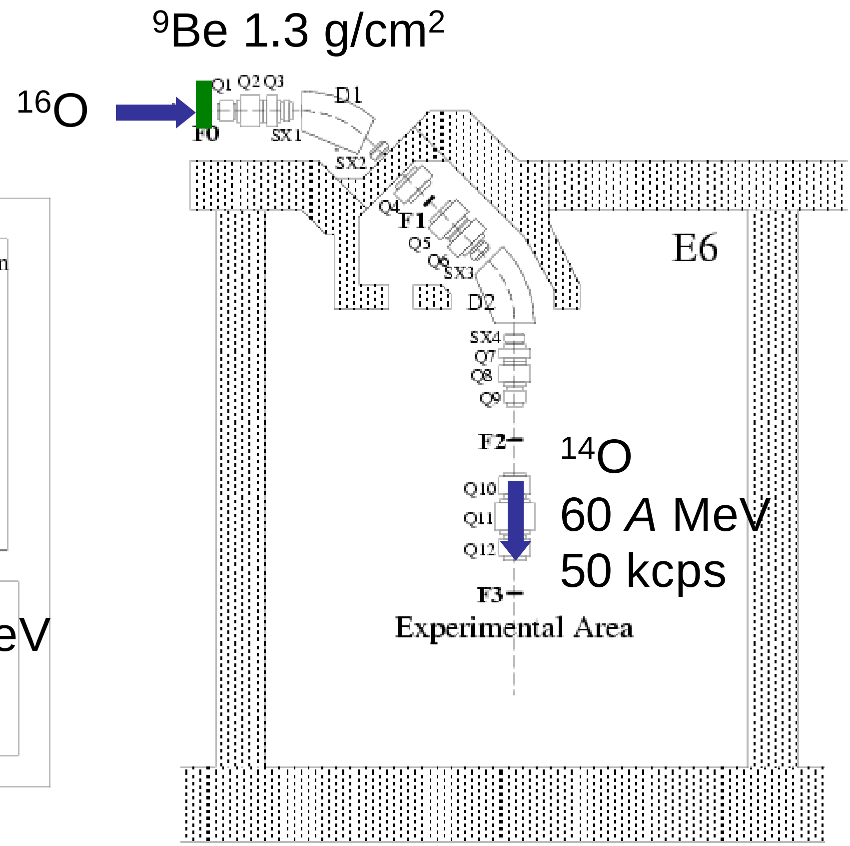
Excitation energy

Threshold energy
of decay channel

RIKEN RIPS



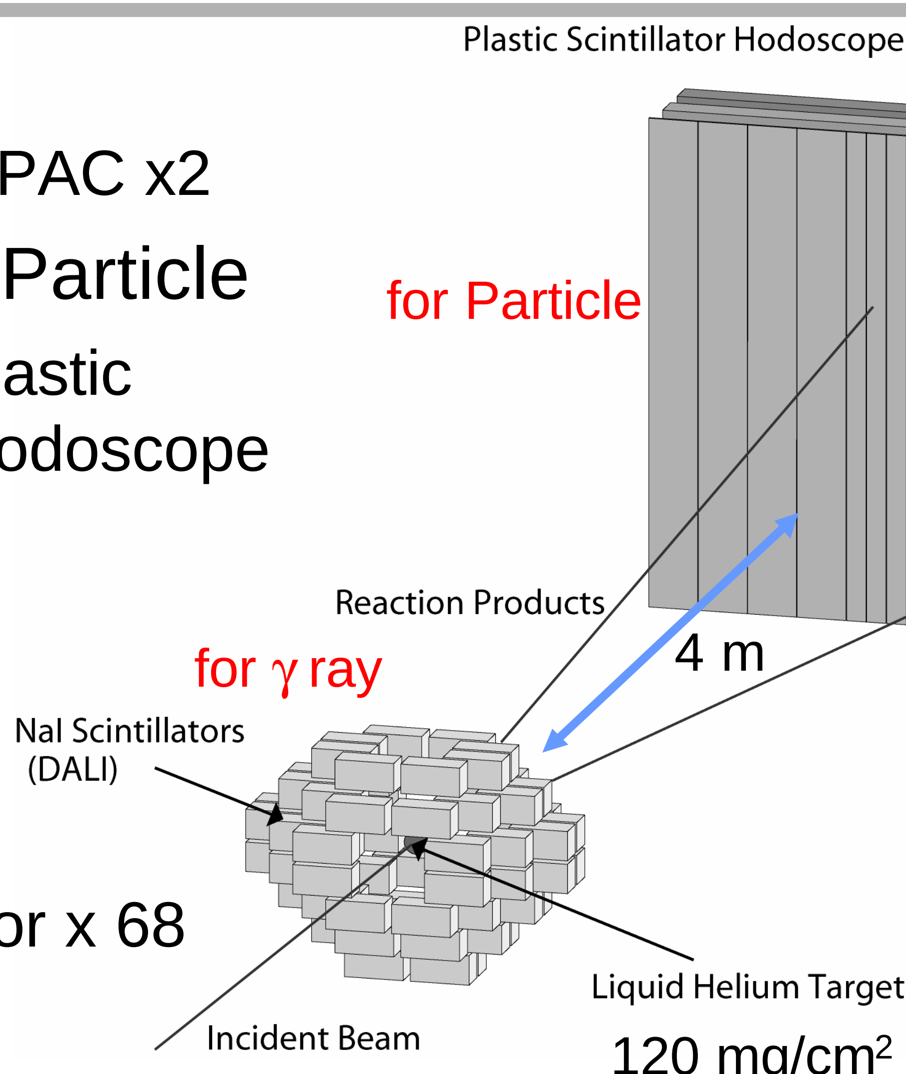
AVF Cyclotron
Ring Cyclotron
E6
RIPS
D
^{16}O
135 *A* MeV



^{9}Be 1.3 g/cm^{2}
^{16}O
Q1 Q2 Q3
D1
F0
SX1
SX2
Q4
F1
Q5
Q6
SX3
D2
E6
SX4
Q7
Q8
Q9
F2
^{14}O
60 *A* MeV
50 kcps
Q10
Q11
Q12
F3
Experimental Area

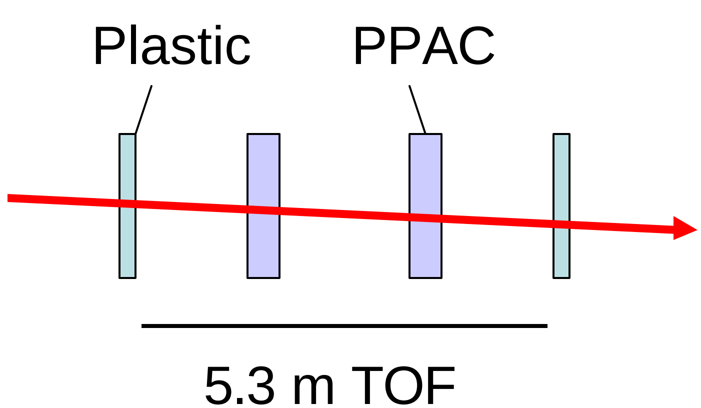
Experimental setup

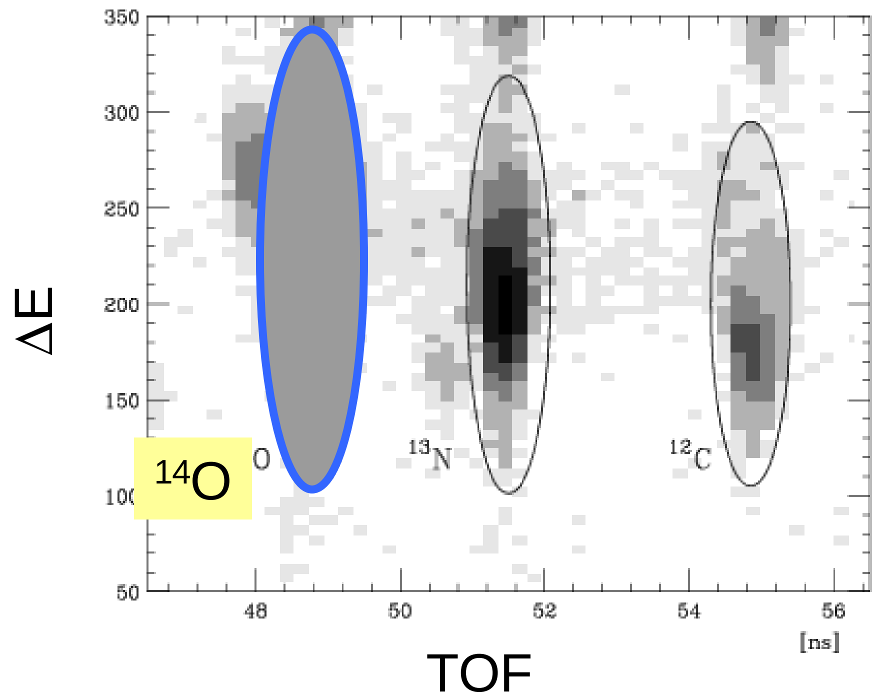
- Beam line
  - Plastic x2, PPAC x2
- For Charged Particle
  - ΔE-E1-E2 Plastic scintillator Hodoscope
  - 1m x 1m
- For γ ray
  - NaI scintillator x 68



Secondary beam

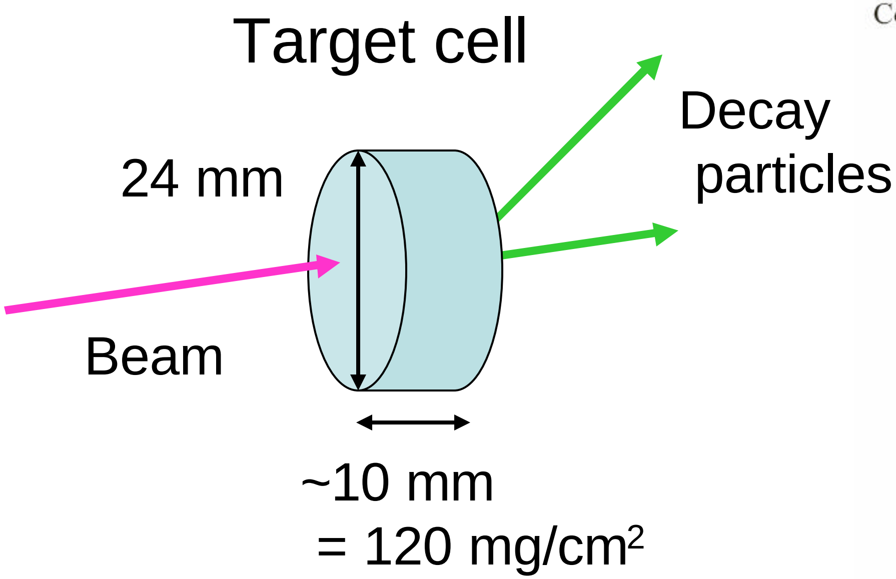
- Secondary ^{14}O beam was produced by projectile fragmentation reaction of ^{16}O and ^{9}Be, and selected by RIKEN RIPS
- Purity = 55 %
- Rate = 50 kcps

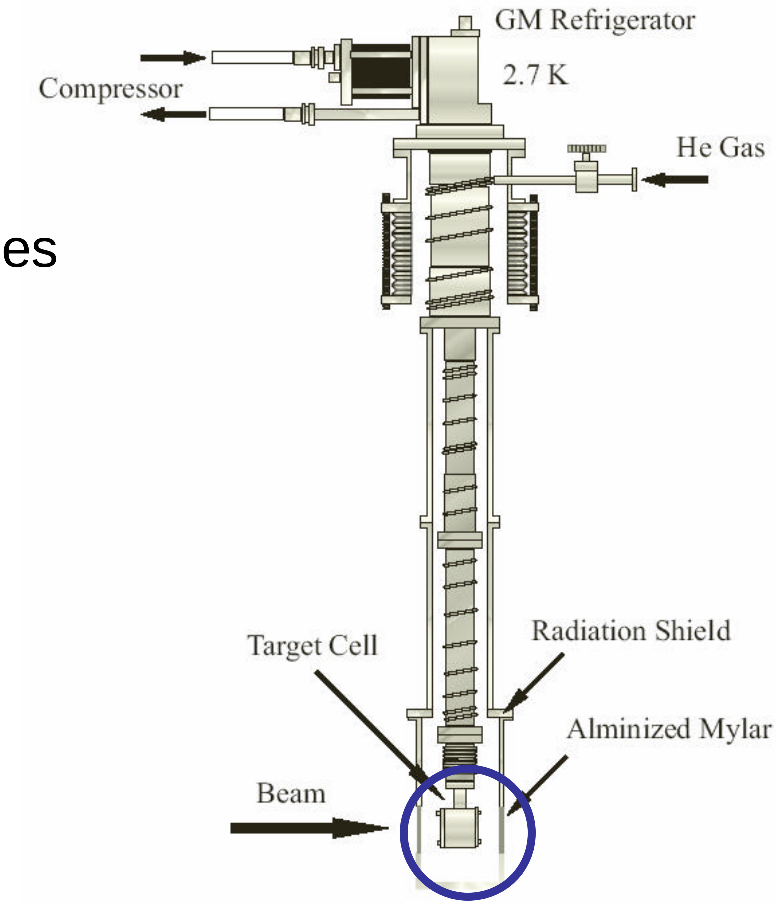




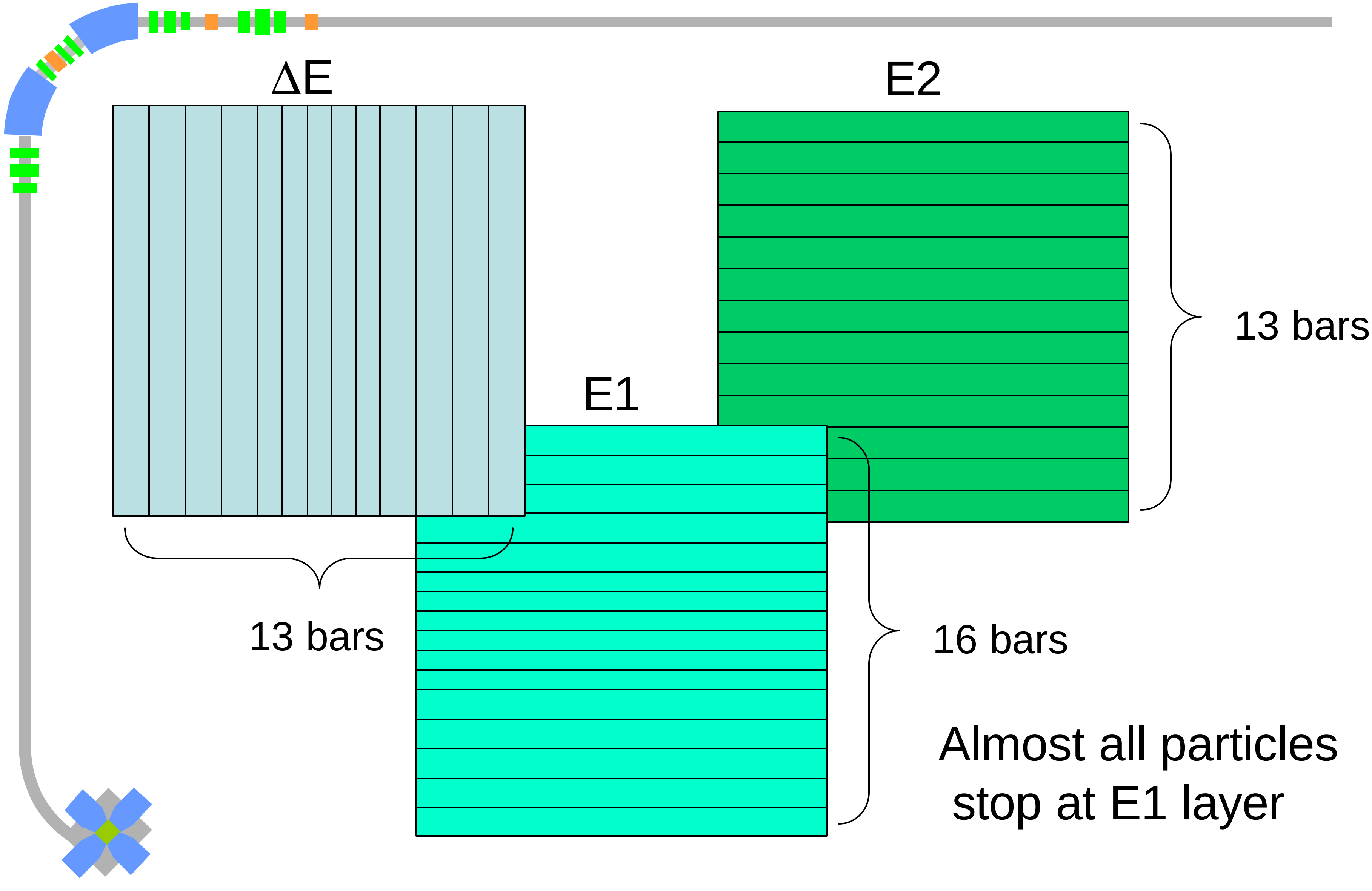
Liquid helium target

- It is difficult to detect recoil α particle



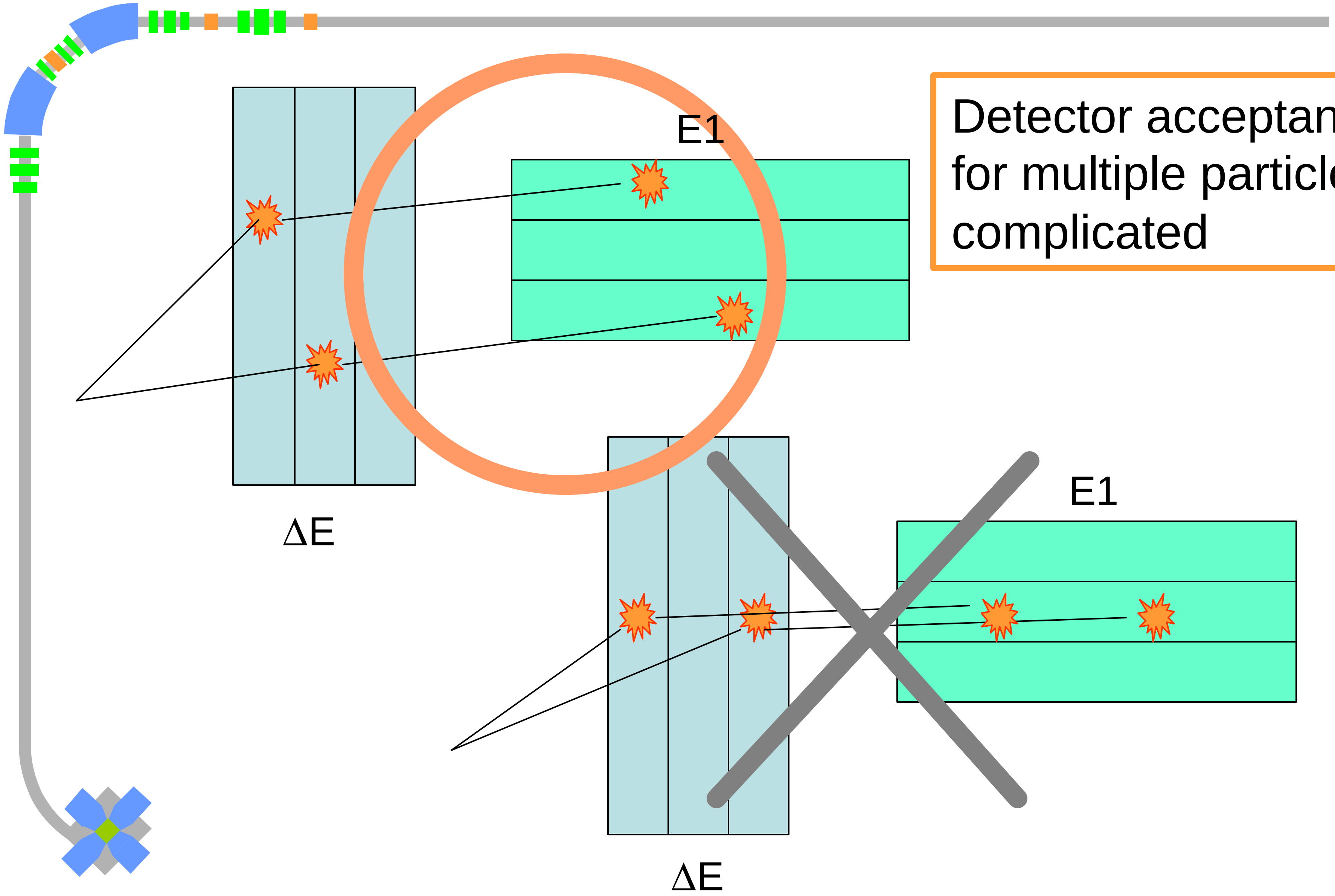


Plastic scintillator hodoscope



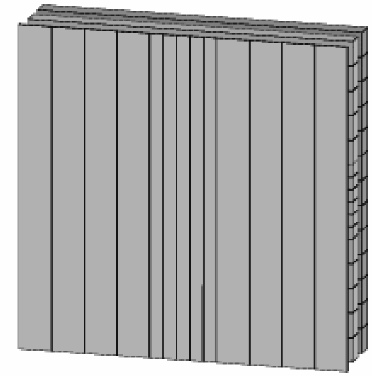
Almost all particles stop at E1 layer

Outgoing particle detection



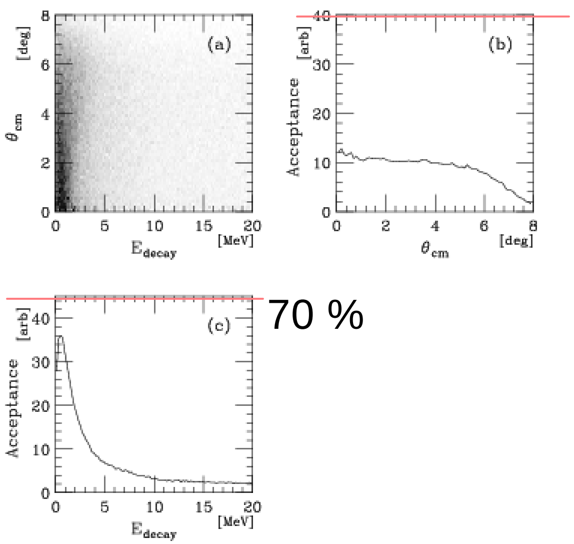
Detector acceptance for multiple particle is complicated

Acceptance (Outgoing particle)



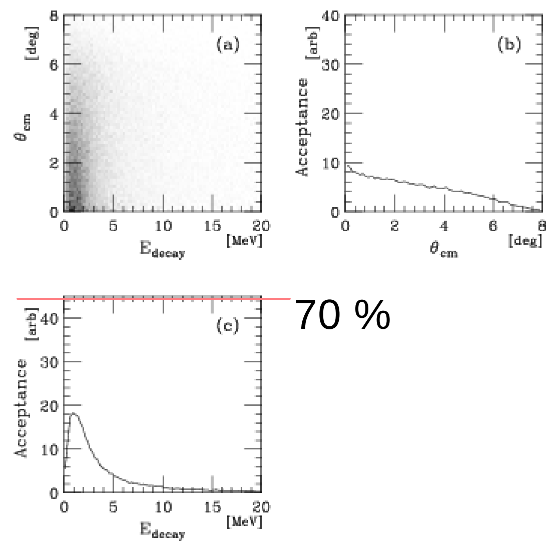
- Monte Carlo simulation
  - for every decay channel

$^{13}N + p$ 50 %



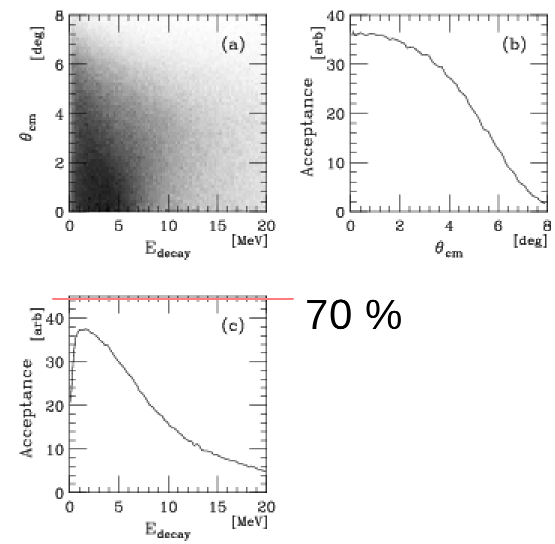
70 %

$^{12}C + p + p$



70 %

$^{10}C + \alpha$

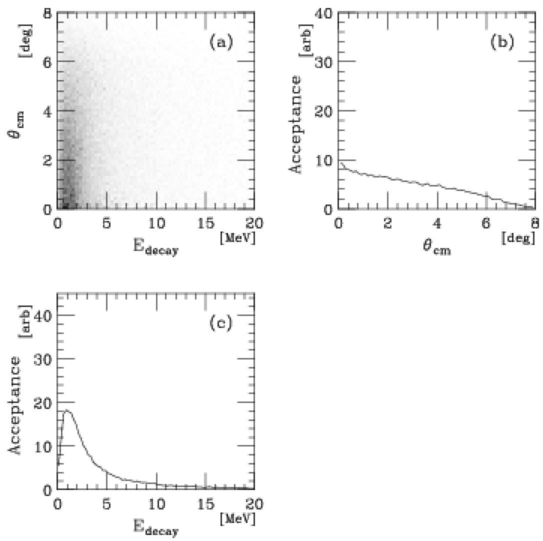


70 %

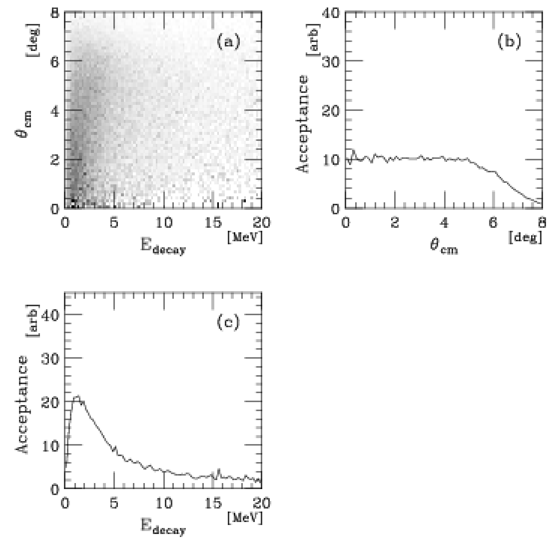
Multiple particle decay

- $^{12}C + p + p$
  - $^{14}O > {}^{13}N + p > {}^{12}C + p + p$, We assumed
  - $^{14}O > {}^{12}C + {}^{2}H > {}^{12}C + p + p$ is fairly rare
  - Acceptances of these two cases are different

$^{14}O > {}^{13}N + p > {}^{12}C + p + p$

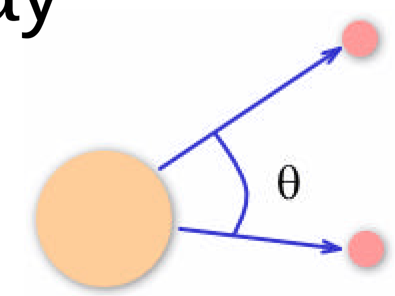


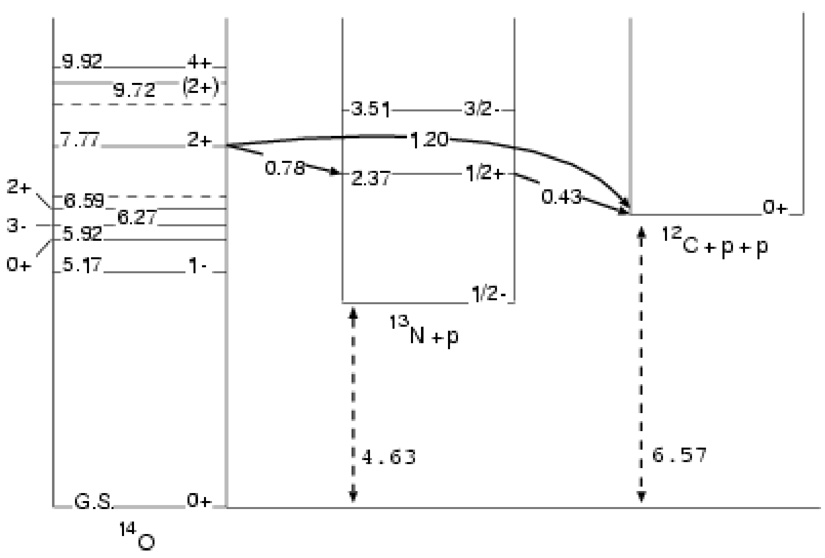
$^{14}O > {}^{12}C + {}^{2}H > {}^{12}C + p + p$

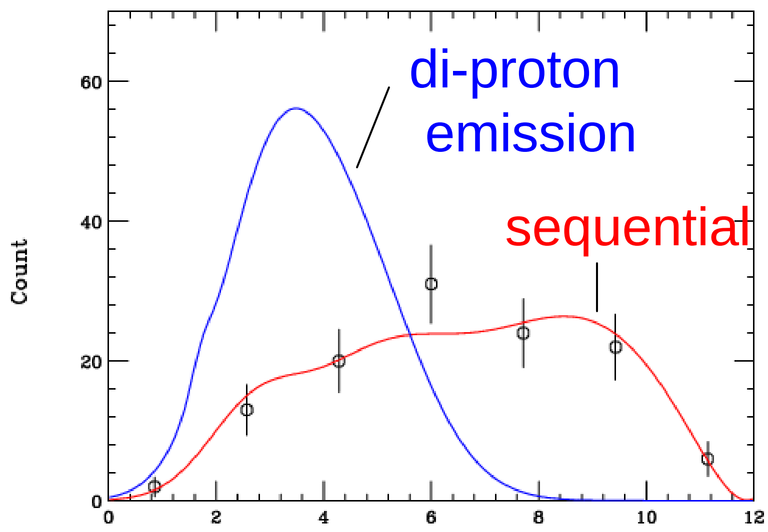


Decay sequence of 7.77 MeV 2^+

- Almost 100 % sequential decay
  - $^{14}O > {}^{13}N + p > {}^{12}C + p + p$
  - $^{14}O > {}^{12}C + {}^{2}H > {}^{12}C + p + p$



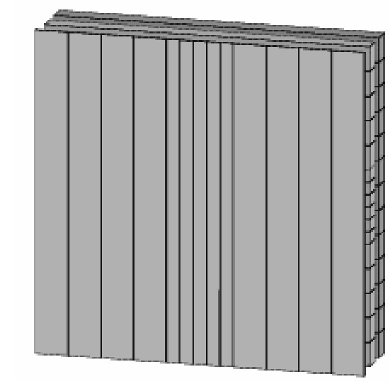


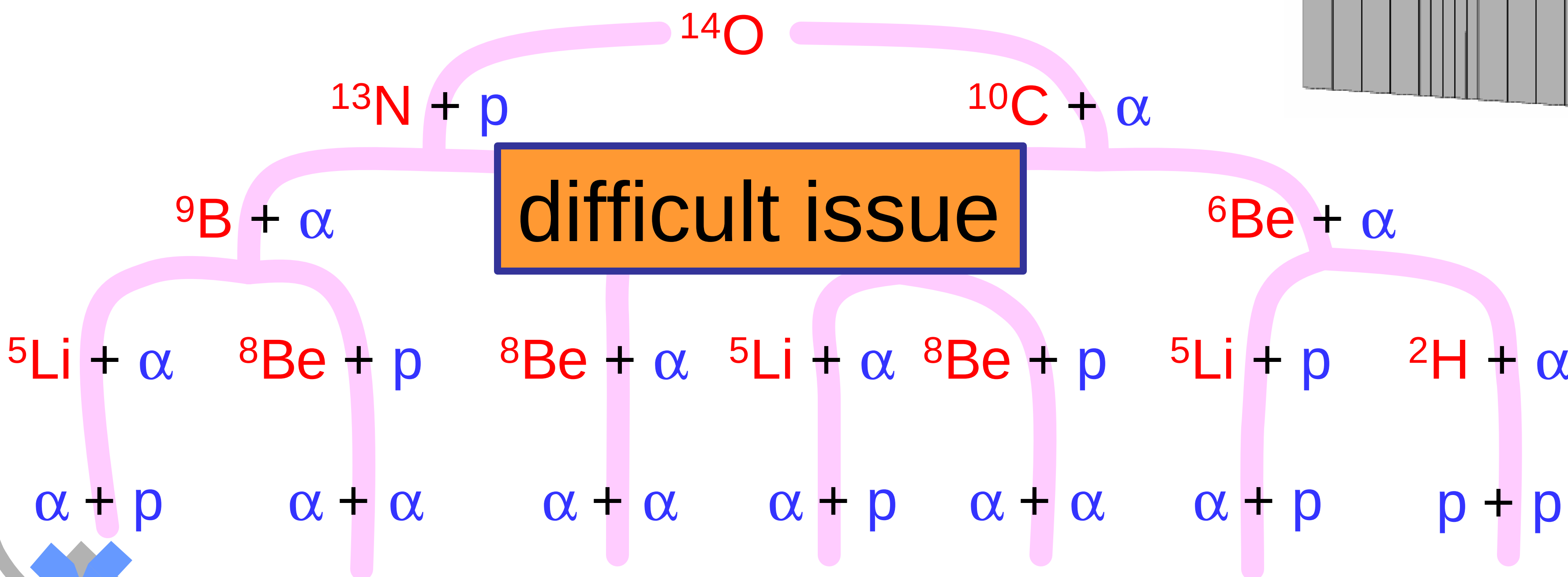


Opening angle of 2 protons

Multiple particle decay

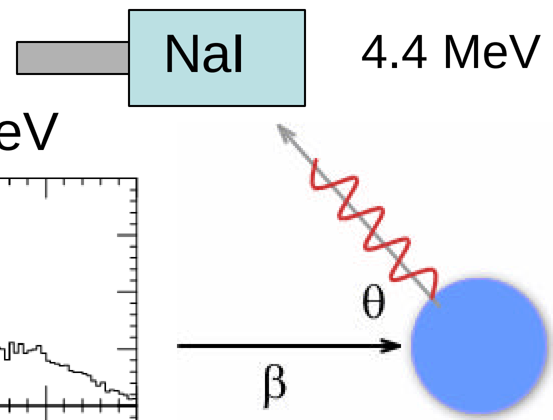
- $^{14}O > \alpha + \alpha + \alpha + p + p$ (13.8 MeV)
  - Detector acceptance is too small
  - We don't know decay sequence



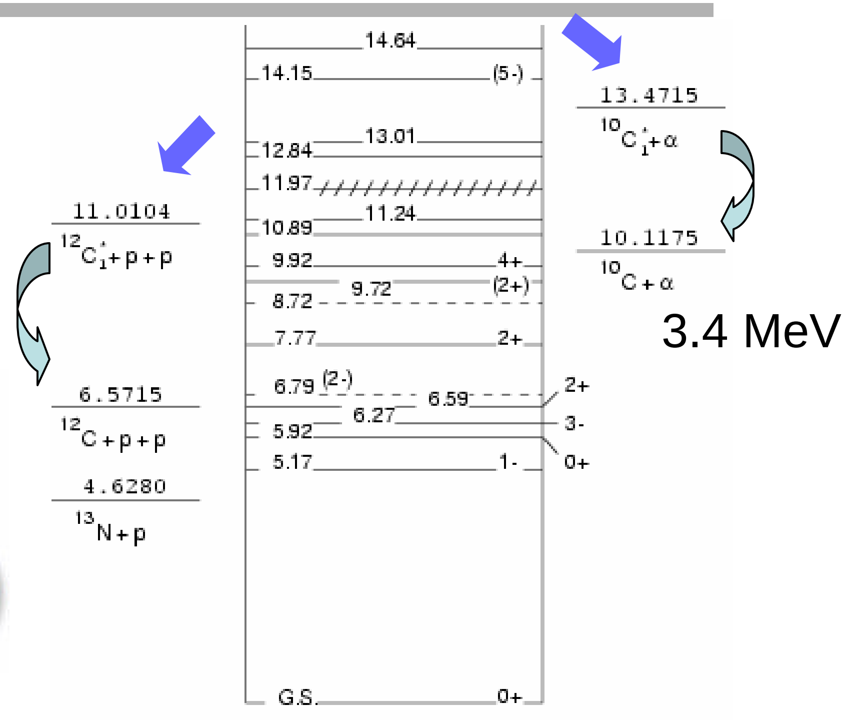


Gamma ray detection

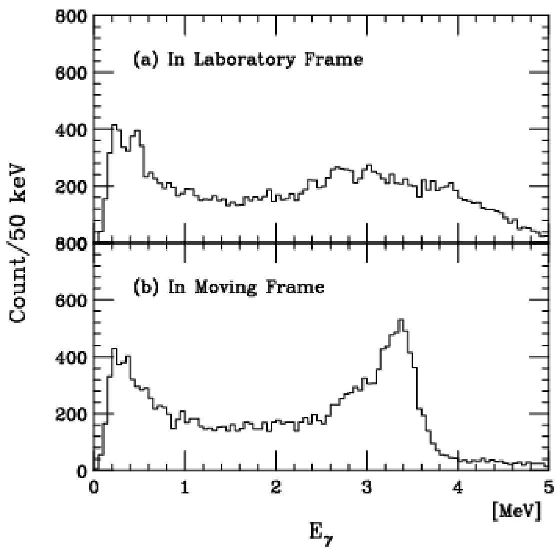
- Doppler correction



4.4 MeV

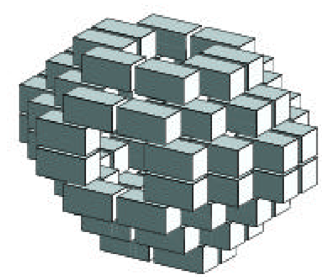


^{10}C 3.4 MeV



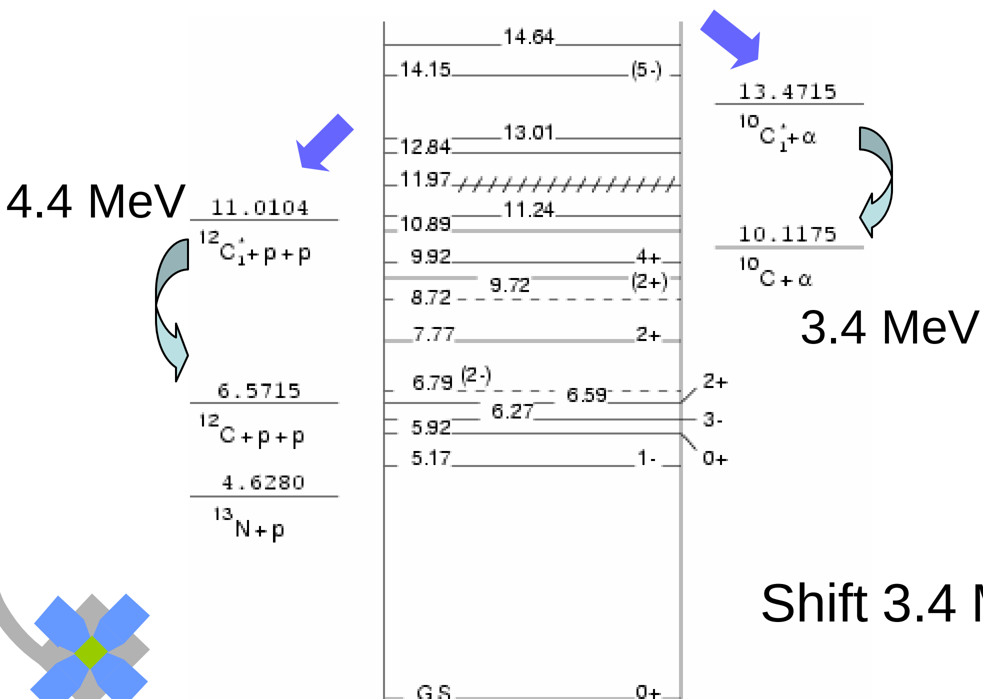
$$E = \gamma \left(1 - \beta \cos\theta\right) E_{obs}$$

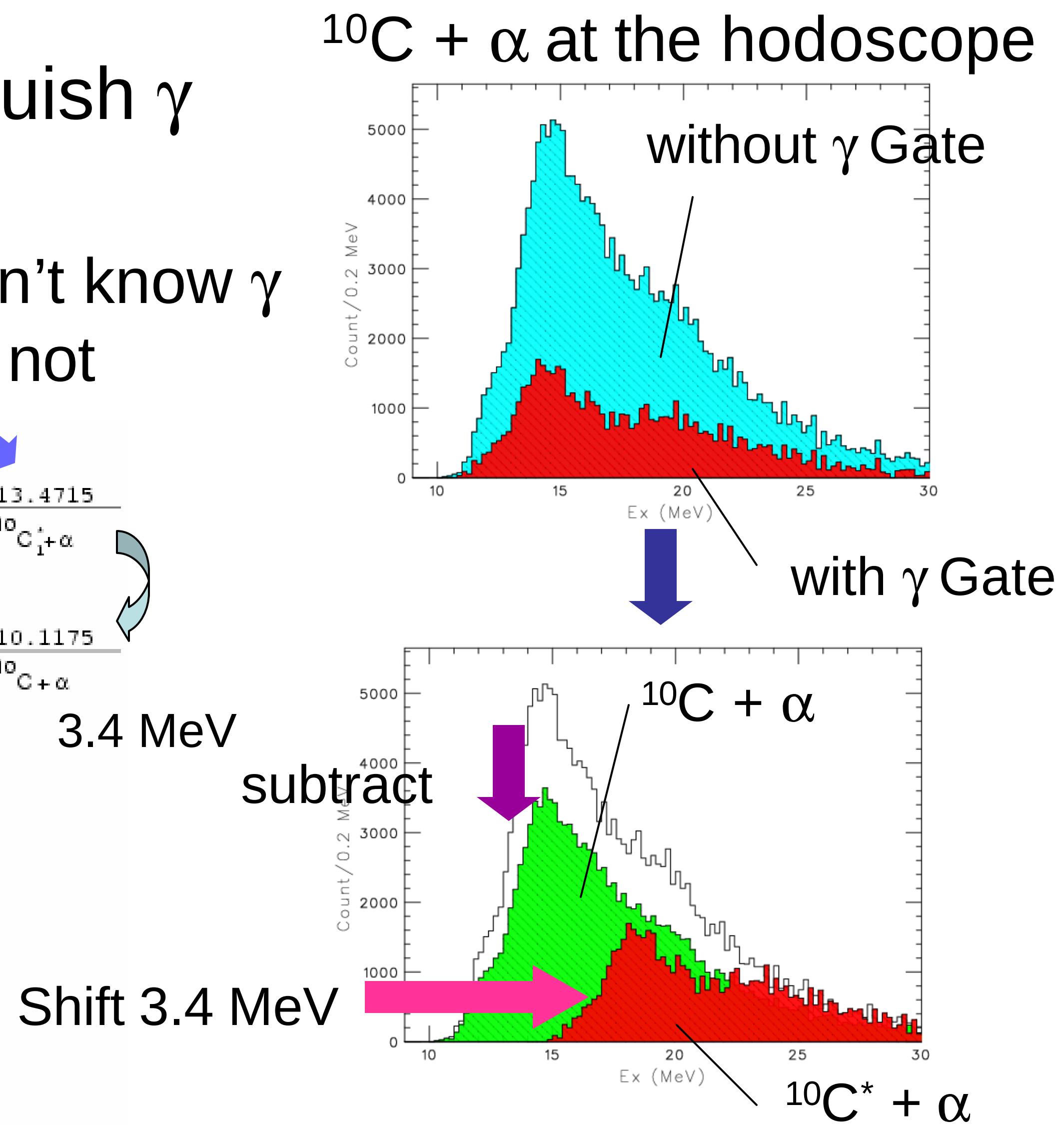
$$\gamma = \frac{1}{\sqrt{1-\beta^2}}$$



Gamma ray from decay particle

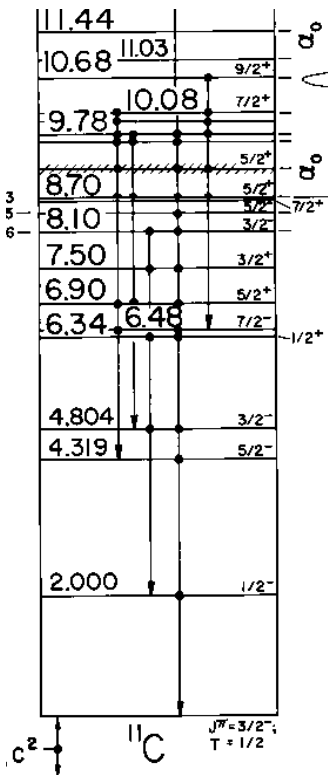
- We have to distinguish γ emission events
  - The hodoscope don't know γ ray was emitted or not

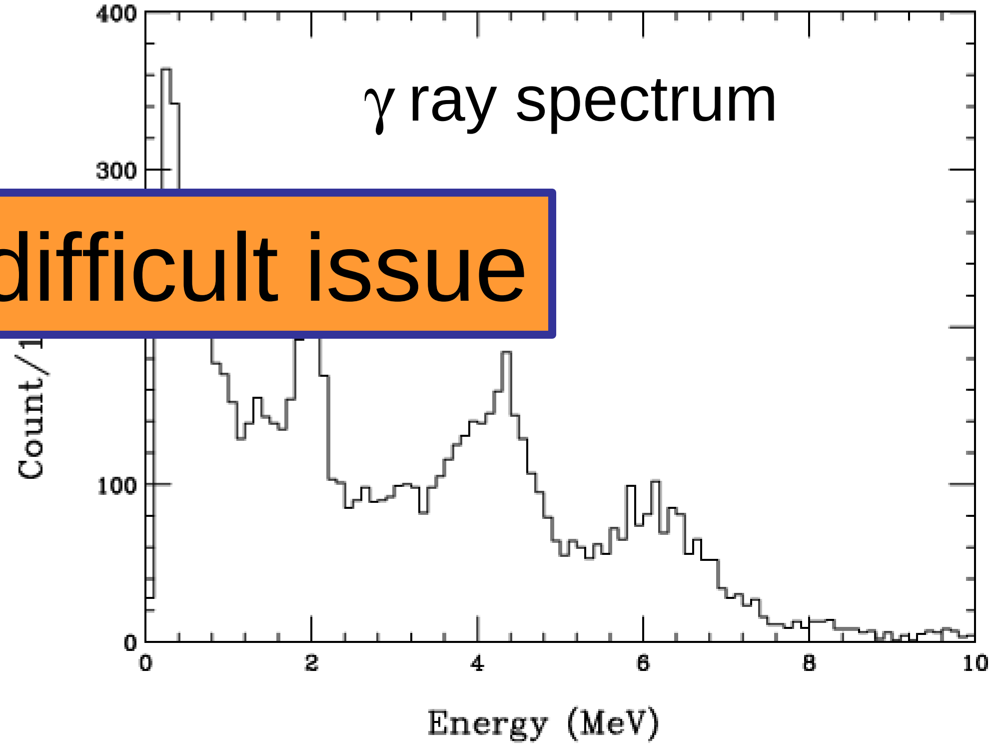




^{11}C + ^{3}He decay channel

- Many γ rays exist, it is difficult to discriminate every energy level completely

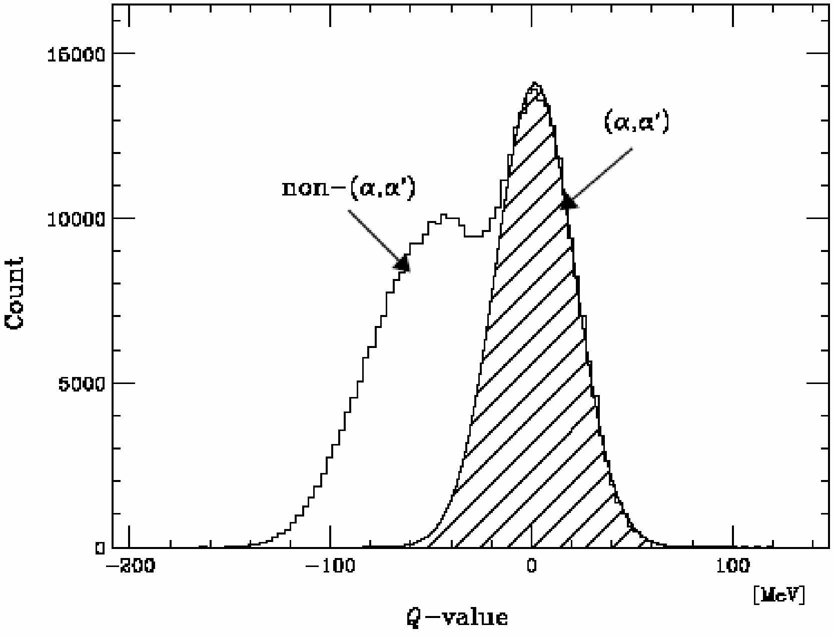




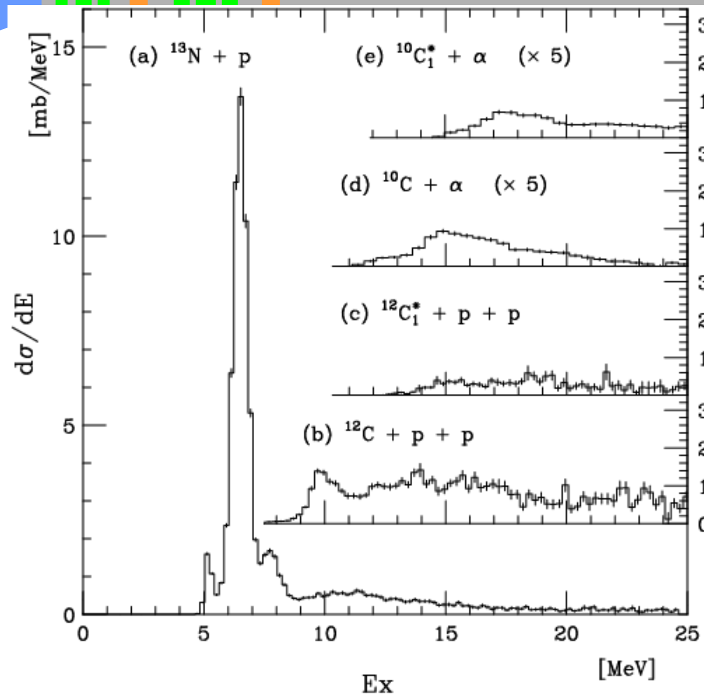
difficult issue

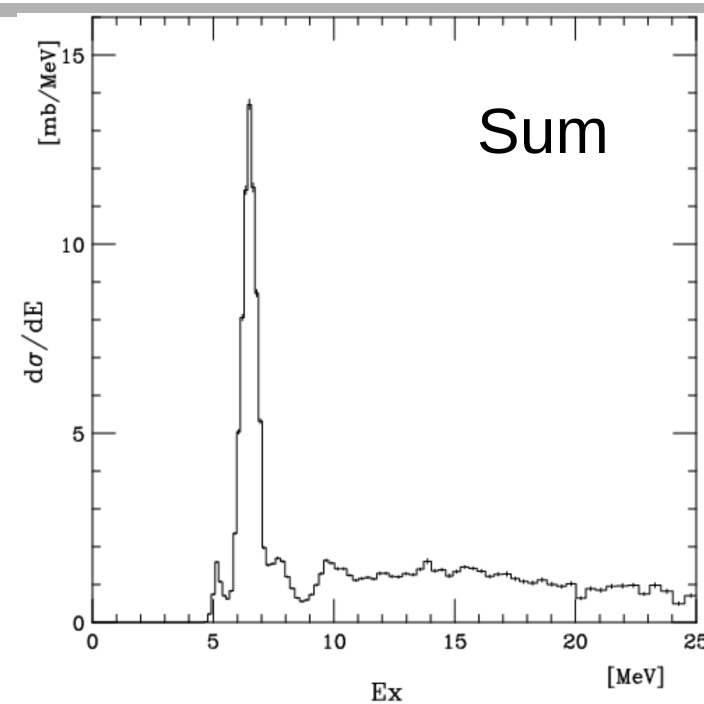
Q-value spectrum

- Poor resolution for *Q*-value
  - α particle is very tight
  - It is possible to discriminate break up channel of α particle



Result - Excitation energy spectrum



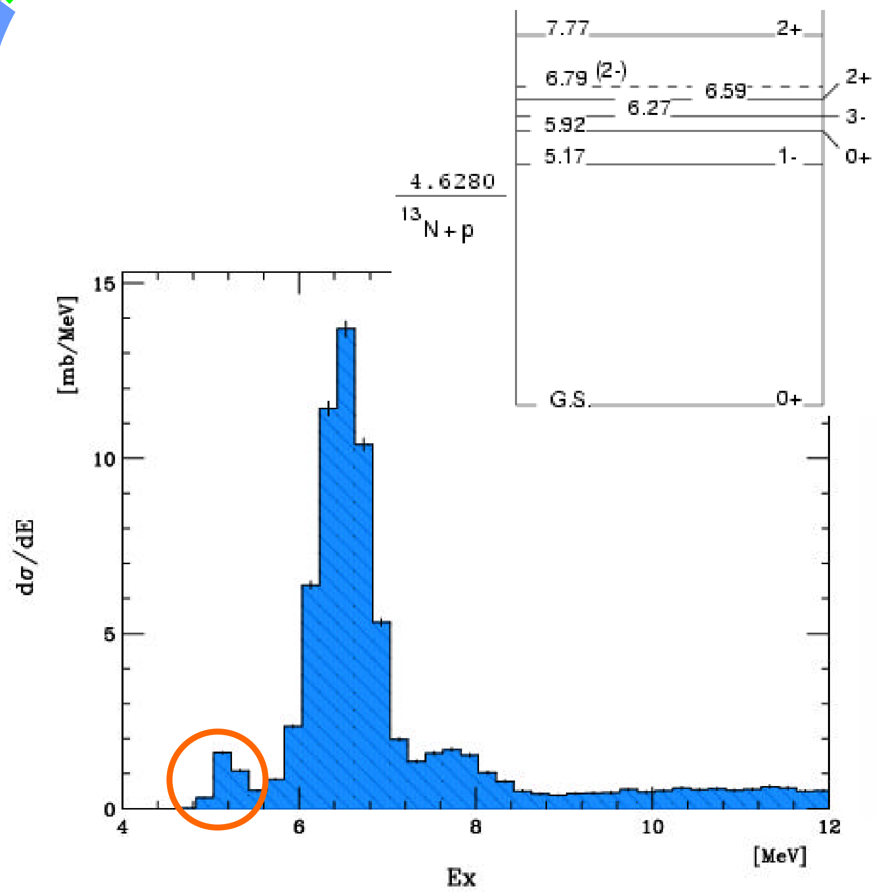


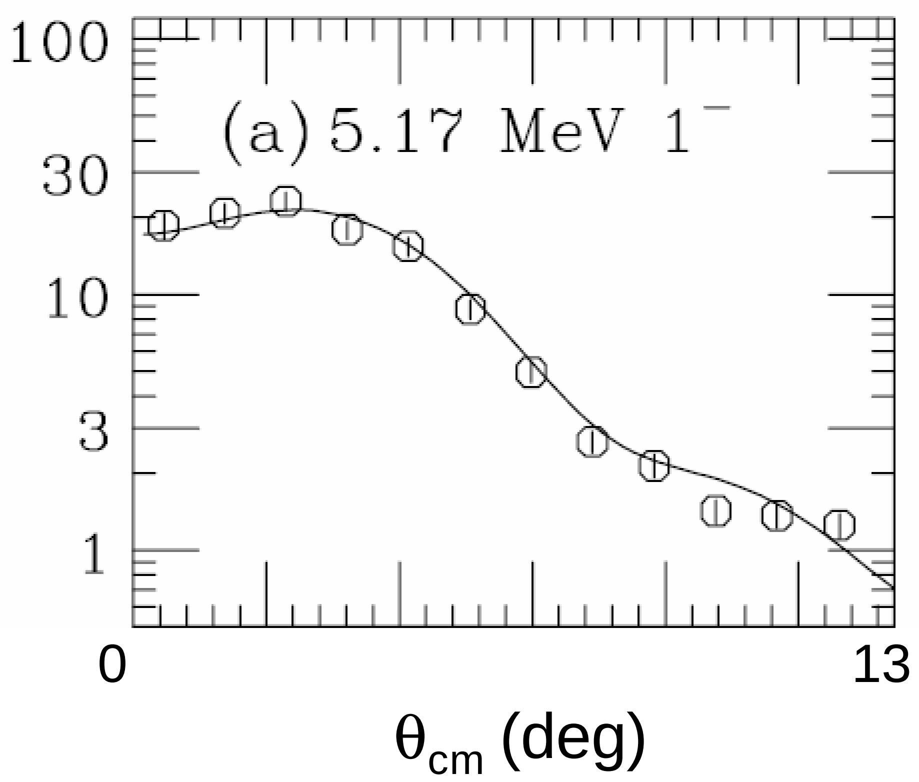
- Measured decay channels
  - ^{13}N + p — 4.6 MeV
  - ^{12}C + p + p — 6.6 MeV
  - ^{12}C* + p + p — 11.0 MeV
  - ^{10}C + α — 10.1 MeV
  - ^{10}C* + α — 13.5 MeV
- Not measured
  - α + α + α + p + p — 13.8 MeV
  - ^{11}C + ^{3}He — 17.6 MeV
  - ^{13}O + n — 21.2 MeV
  - ⋮

DWBA analysis

- In order to deduce isoscalar multipole strength
  - Multipole decomposition analysis with the DWBA calculation (MD analysis)
- DWBA calculation for 60 *A* MeV α
  - Single-folding Model for optical and transition potentials was employed
    - A. Kolomiets et al., Phys. Rev. **C61** (2000) 034312
    - G.R. Satchler, Nucl. Phys., **A472** (1987) 215
    - M.N. Harakeh el al., Phys. Rev. **C23** (1981) 2329
  - Computer code ECIS97 was used
    - J. Raynal, unpublished

DWBA calculation for 5.17 MeV 1⁻





Multipole Decomposition Analysis

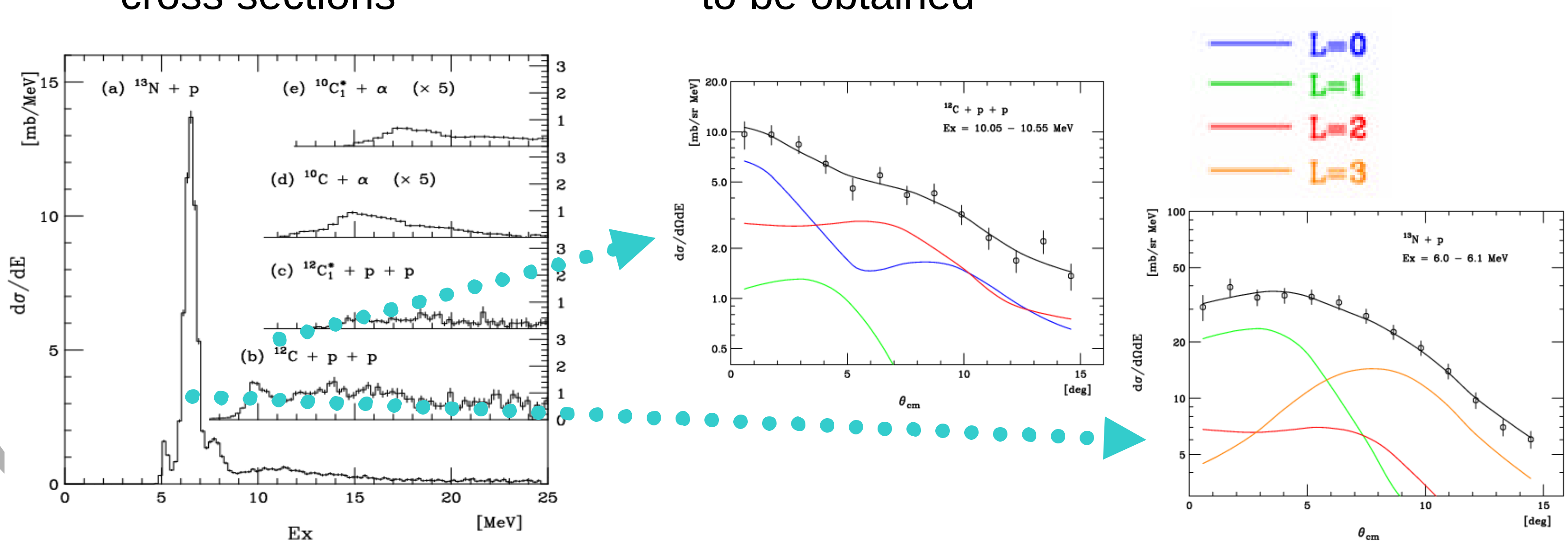
- Discriminate multipole components from angular distribution

$$\left(\frac{d^2\sigma}{d\Omega dE}\right)^{EXP} = \sum_L a_L(E) \left(\frac{d^2\sigma}{d\Omega dE}\right)^{DWBA}$$

Experimentally obtained cross sections

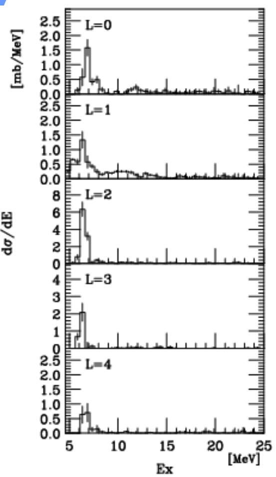
EWSR fraction to be obtained

Multipole components DWBA caluclration 100% EWSR

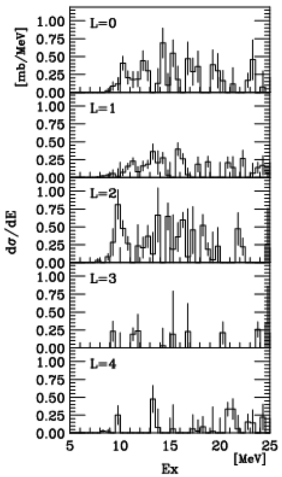


Result - Decomposed cross-section

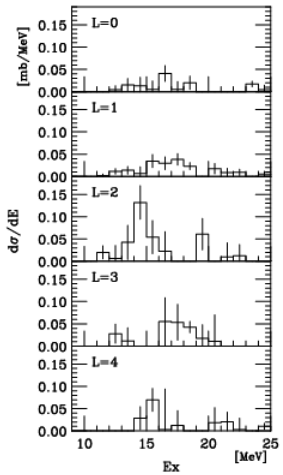
$^{13}N+p$



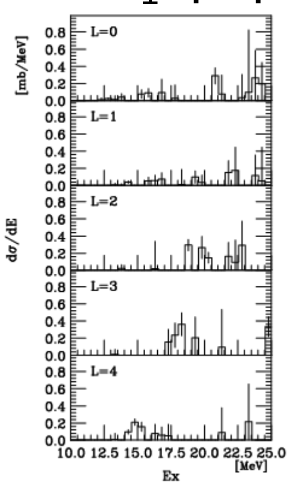
$^{12}C+p+p$



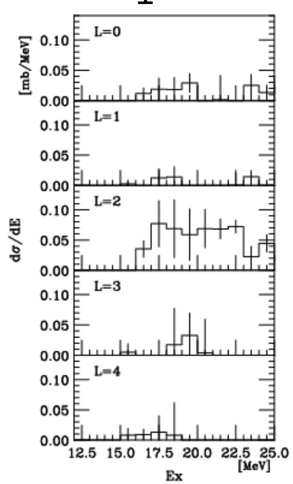
$^{10}C+\alpha$



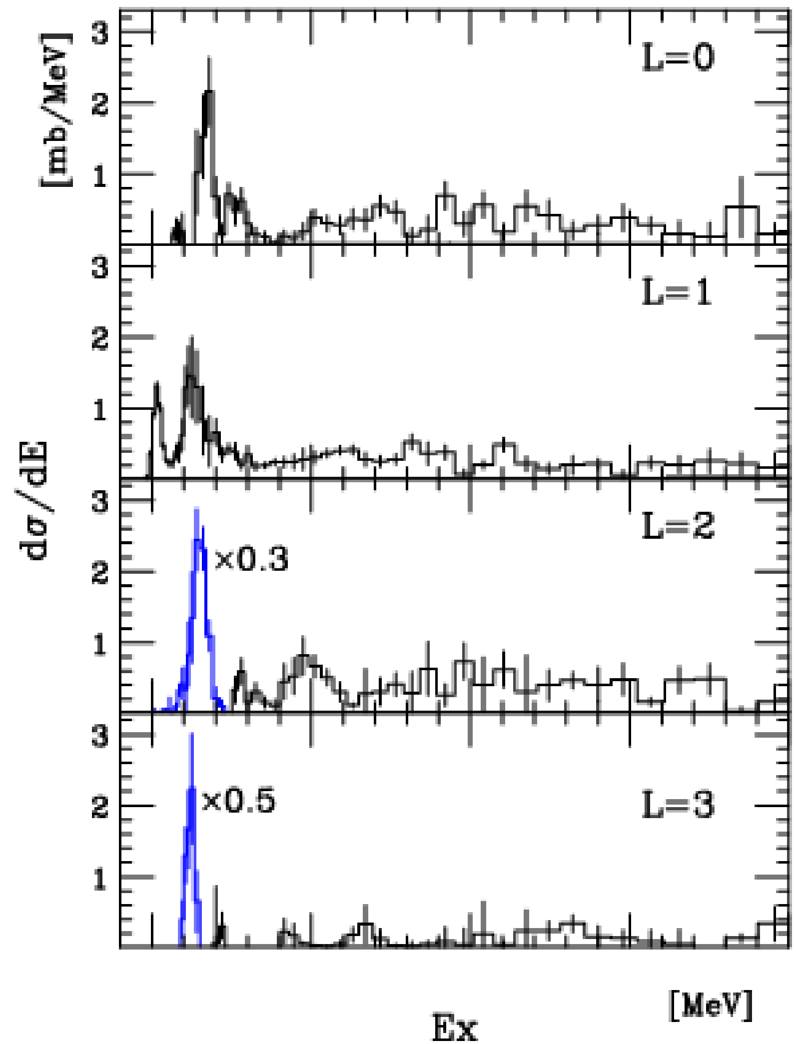
$^{12}C^*_1+p+p$



$^{10}C^*_1+\alpha$



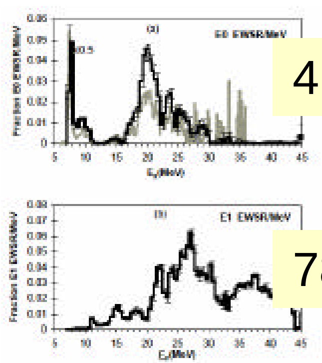
Total cross-section



EWSR fraction for monopole and dipole

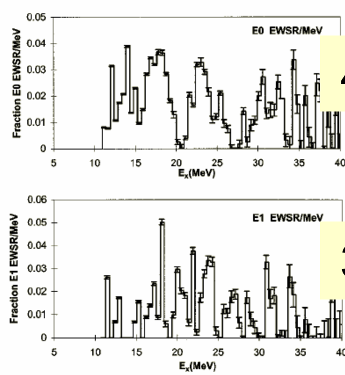
- Fragmented distribution is in common with stable nuclei
  - It is common feature in light nuclei regardless stable or unstable

^{12}C



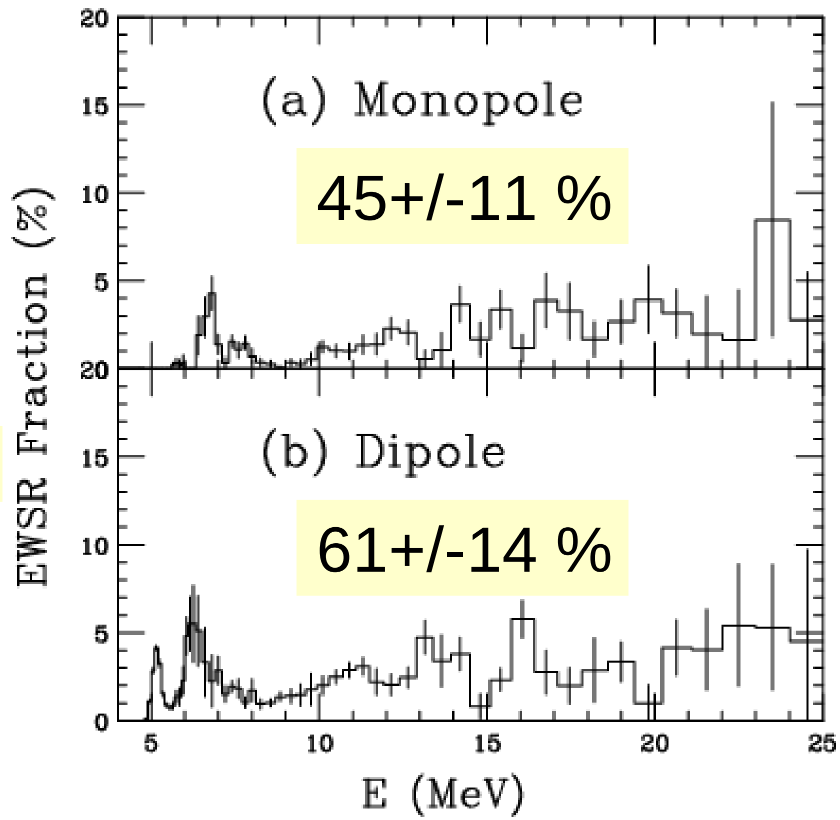
5 - 45 MeV

^{16}O



5 - 40 MeV

^{14}O



5 - 25 MeV

- B. John et. al., Phys. Rev. **C68** (2003) 014305
- Y.-W. Lui et. al., Phys. Rev. **C64** (2001) 064308

Summary

- Inelastic α scattering on ^{14}O at 60 *A* MeV
  - Excitation energy spectrum was obtained with wide energy range using invariant-mass method
  - With some difficulties
- Isoscalar monopole and dipole strengths were deduced
  - Multipole decomposition analysis
    - Inelastic α scattering in inverse kinematics can obtain isoscalar multipole strengths
  - Fragmented strength distributions are in common with stable nuclei
- It is difficult to measure all decay channels completely
- Can we obtain incompressibility or other information from exclusive decay channel ?